

APPENDIX B. MATERIAL AND ENVIRONMENTAL DATA

B.1 MATERIALS TESTS-SUMMARY

B.1 .1 Purpose

The intent of the following tests was to quantitatively assess the effect on the quality of the received radar signal when the radar's "view" of a target is obstructed by various materials found on a car or in a roadway situation.

B.1.2 Procedure

The FLAR was placed approximately 1 meter off the ground on a level surface. A 5 dB corner reflector was then placed 20 meters away from the FLAR, at about the same height on a Styrofoam pillar. A reading of the corner reflector without any obstruction was taken to get a baseline from which all other tests could be compared. About 1.5 seconds of data were collected (about 200 samples) using ERIM's Data Collection Software. The baseline test was verified, as were all others, by recording the test with a SVHS camera.

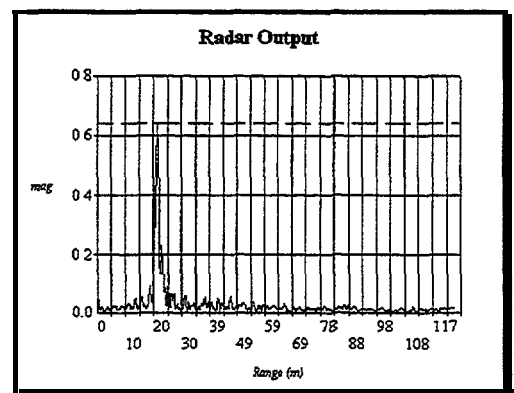
The next step was to test the effect of individual materials on the FLAR sensor. A large piece of the material to be tested was placed in the beam of the sensor. Another 1.5 seconds of data were collected using the ERIM Data Collection Software. The tests were repeated using the following pieces of material:

glass, Plexiglas, epoxy glass, thin cardboard, thick cardboard (about 1/3" thick), TPO (a plastic material often used in automotive bumpers), plywood, and RAM (radar absorbing material).

After the tests were completed, the data was analyzed on the ERIM Analysis PC using the ERIM's FUR Analysis Software. The AGC attenuation values were recorded and a Matlab script was written to analyze and average the return levels. Outputs from the Matlab analysis are attached.

The plot in Figure B-1 (from the analysis PC) shows the return from a 5 dBsm corner reflector located just over 20 meters from the radar. The automatic gain control (AGC) setting is given below the plot. The AGC is a variable gain amplifier used in the radar receiver circuit to increase the dynamic range of the A/D converters. The AGC setting must be compensated for when comparing relative return levels. The attenuation value (in dB magnitude) associated with the AGC setting is also provided for each plot. The level of attenuation is referenced to the maximum gain of the amplifier.

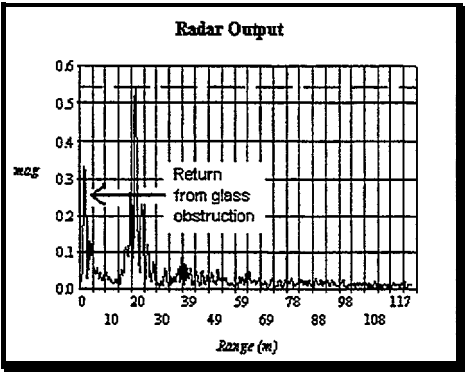
The plot in Figure B-2 shows the return from a 5 dBsm corner reflector located just over 20 meters from the radar, with a sheet of glass placed about 1 meter from the RADAR at an angle of about 15 degrees from vertical. The automatic gain control (AGC) setting and corresponding magnitude



AGC: 4.15391 volts
Attenuation: 19.90 dB

Figure B-1. Baseline Test

attenuation is given below the plot. The reflected signal from the glass can be seen in Figure B-2 as the smaller of the two spikes.



AGC: 3.90599 volts
Attenuation: 3.63 dB

Figure B-2. Glass (15 degree angle)

B.1.3 Results

Three effects were observed during the material obstruction tests: (1) target signal strength attenuation, (2) direct reflection from the material being tested, and (3) creation of multipath returns. Each of these effects are discussed below. A rudimentary discussion of reflection and refraction mechanisms is provided at the end of this section.

Attenuation

Table B-1 summarizes the attenuation results of the material tests. The return levels and AGC settings for each collection are provided. These measured parameters were used to calculate the “AGC adjusted voltage” values which are then compared to determine the attenuation levels. The “Baseline” measurement was used as the reference for each attenuation calculation. Note that the attenuation levels provided are for “two-way” propagation. In other words, the radar signal passed through the material under test twice--once on transmission, and once after it was reflected off of the target in the scene.

Figure B-3 illustrates the relative attenuation levels listed in Table B-1 . The materials are listed from lowest attenuation level to highest. Note that the RAM attenuation level represents the maximum attenuation level for the given test set-up (e.g., size and distance of target)- Returns from the reference reflector placed in the scene were always observable in the radar data except for tests with the RAM. Even in tests with the plywood as the obstructing material, the FLAR was still capable of detecting the 5 dBsm reference target at 20 meters.

Table B-1. Attenuation

Material Description	Measured Return Volts	AGC Control Setting (v)	AGC Mag. Attenuation (dB)	AGC Adjusted Return Volts	Two-Way Power Attenuation (dB)
Baseline	0.458	4.154	-19.9034	1.4403	0.0
Clear Plexiglas	0.405	3.956	-5.9292	0.5698	8.1
Thin Cardboard	0.4	3.906	-3.6324	0.4930	9.3
Windshield Glass (15 degrees)	0.381	3.906	-3.6324	0.4696	9.7
Epoxy Glass	0.343	3.906	-3.6324	0.4228	10.6
Thick Cardboard (corrugated)	0.188	3.906	-3.6324	0.2317	15.9
TPO	0.17	3.906	-3.6324	0.2095	16.7
TPO (15 degrees)	0.163	3.906	-3.6324	0.2009	17.1
Plywood (.75")	0.056	3.906	-3.6324	0.0690	26.4
RAM	0.05	3.906	-3.6324	0.0616	27.4

Two-way Power Attenuation (dB)

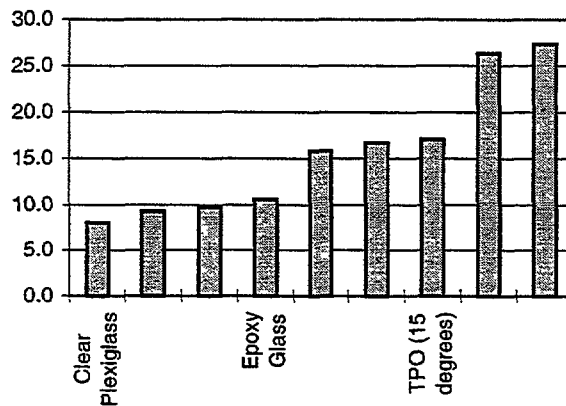


Figure B-3. Attenuation Levels

The two-way attenuation levels vary from 8.1 dB for the clear plexiglas to over 17 dB for the TPO (a plastic-type material commonly used for bumpers and facia styling) to over 26 dB for the plywood.

Reflections

In addition to attenuating the return levels from the reference reflector, many of the materials produced a direct radar signal return (i.e., the material reflected the radar energy. The materials producing the largest reflections were the windshield glass and TPO materials. Note that these reflection levels were highly dependent upon the orientation between the FLAR and the material sample. The plots

at the end of this section indicate that these reflection levels can be nearly equal to the return level from the reference reflector. Of course the material samples were at a much closer range than the reference reflector—1 to 2 meters for the material samples versus 20 meters for the reference reflector.

Much lower direct reflections were observed from the cardboard, plexiglās and plywood materials. While these reflections were clearly evident, they were not much above the noise floor of the FLAR.

Multipath

In addition to the reflections and signal attenuation, several of the material samples were observed to produce multipath returns from the reference reflector. Figure B-4 shows a diagram of how an obstructing material can cause a multipath return. Some level of energy is refracted by the material and directed along an indirect path to the target. Since the distance the radar signal must travel the indirect path is longer than that along the direct path, the resulting range reading from the radar will be greater than the actual direct range to the target.

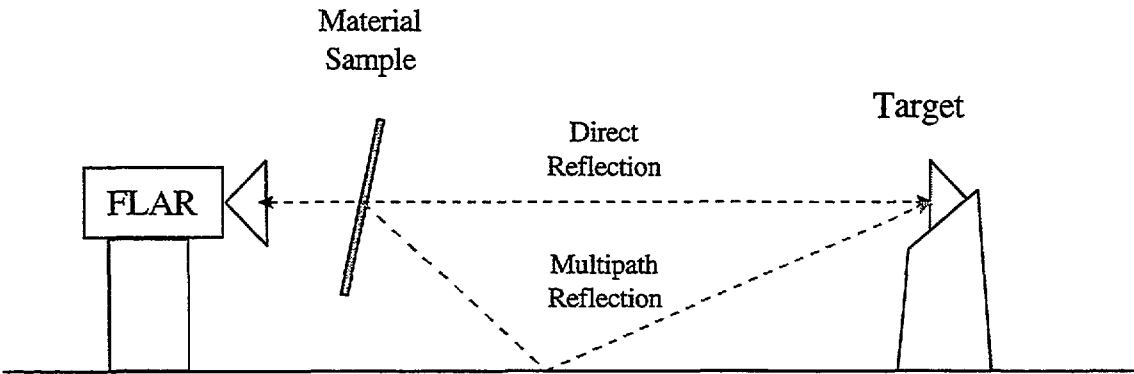


Figure B-4. Multipath Reflection

Figure B-5 shows the radar returns collected with a TPO material sample oriented 15 degrees off vertical. The multipath returns from the reference reflector are clearly evident. These effects were also observed for other materials tested. The effect of this phenomenon is that the peak level return from the reference reflector is decreased and false returns are produced. See the plots attached for more multipath examples.

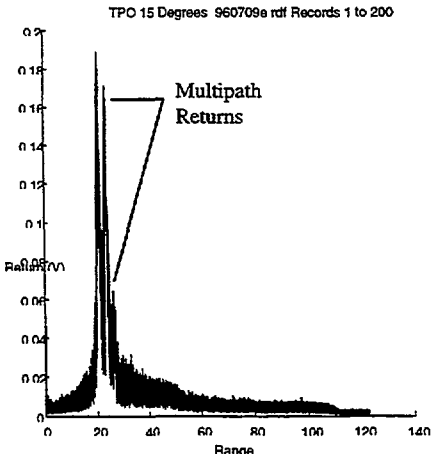


Figure B-5. Multipath Returns From TPO Material at 15 Degree Incident Angle

B.1.3.1 Reflection and Refraction Mechanisms

Radar signals are reflected by two different forms of media: conducting and non-conducting. When a wave strikes a conducting medium, the electric field of the wave induces an inverse electric field in the medium. This electric field then radiates a wave back at the radar sensor, as a returned signal.

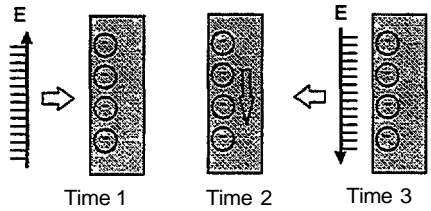


Figure B-6. Reflection From Conductive Surface

A non-conducting medium also reflects RADAR signals, but not always all of it. The amount of the signal that is reflected back at the sensor depends on the ratio of the dielectric constants (K_c) of the two media (in this case we use air as a medium). The dielectric constant of a medium determines the division between the electric and magnetic fields of a wave. When the RADAR signal enters a new medium the dielectric constant readjusts the wave's electric and magnetic field ratio. In order to do this, some of the signal must be reflected.

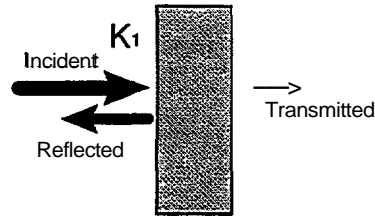


Figure B-7. Reflection From Non-Conductive Surface

If the angle of incidence (θ_i) is greater than zero when a wave enters a new region with a different dielectric constant, then the wave is deflected, otherwise known as refraction. The deflection increases the angle of incidence of the wave proportional with the ratio of the dielectric constant of the two media.

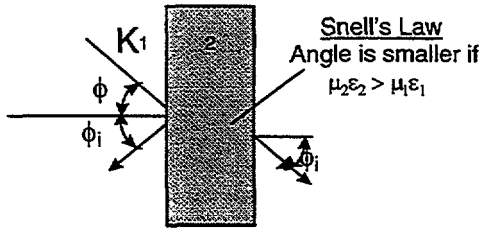


Figure B-8. Reflection and Refraction Angles

The level of return of the reflected signal, also depends upon the orientation and shape of the object. The orientation and shape of the object determines the reflected signal's direction. Figure B-9 illustrates how orientation affects signal return level.

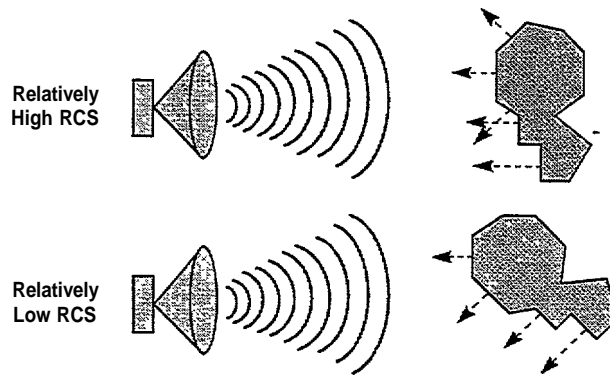


Figure B-9. Object Orientation Effect on Reflected Signal

B.1.4 Conclusions

The tests discussed in this section have evaluated the effects of various materials on the target return levels for a 94 GHz radar. Figure B-3 summarizes the test results. The power attenuation level is provided for each material tested. Again, these attenuation levels correspond to the effects on a 94 GHz radar, but similar results can be expected at 77 GHz. Key observations of the test include:

- All materials tested allowed some portion of the radar signal to pass through the material and attenuated the RADAR signal to some degree.
- Except for the RAM material, the return from the reference reflector was still observable.
- Some materials reflected energy at certain orientations which was observable.
- Some materials produced multipath returns at certain orientations.

For styling, automotive radars will have to be integrated into the overall vehicle structure. This means the radar antennas will most likely be covered by some type of material, therefore knowledge of the absorption, transmittivity, and reflection characteristics of various materials is critical to successful implementation of automotive radar sensors.

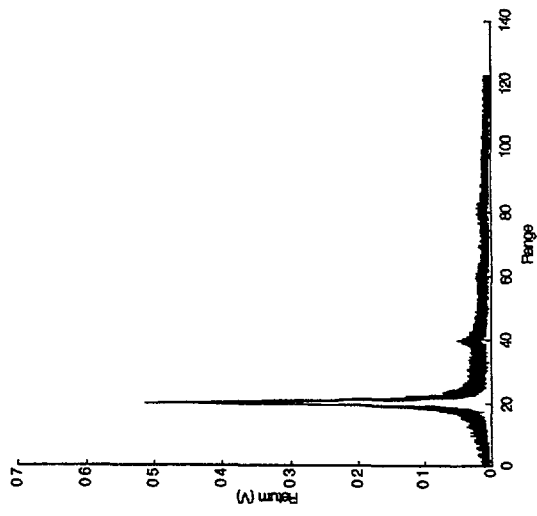
These materials tests identify issues which must be addressed to successfully integrate a radar into the automobile. First of all, if the radar antennas are to be concealed by some material, the signal attenuation resulting from the chosen material must be compensated for to maintain the required radar sensitivity. This can be easily done by increasing the transmit power of the radar. However, this may have serious cost implications. Therefore, the concealing material must be carefully selected. Typically suggested locations for automotive radars would place the sensors either behind the plastic material of the front fascia or grill, or behind the glass of the windshield or headlights.

The quantitative data of these tests (see Figure B-3) indicate that placing the sensor behind a slanted windshield may produce less attenuation than placing it behind TPO-type plastic. An even better solution is to place it behind clear Plexiglas. Another option is to utilize specially fabricated material which exhibits very low attenuation, however, this could add cost to the system implementation.

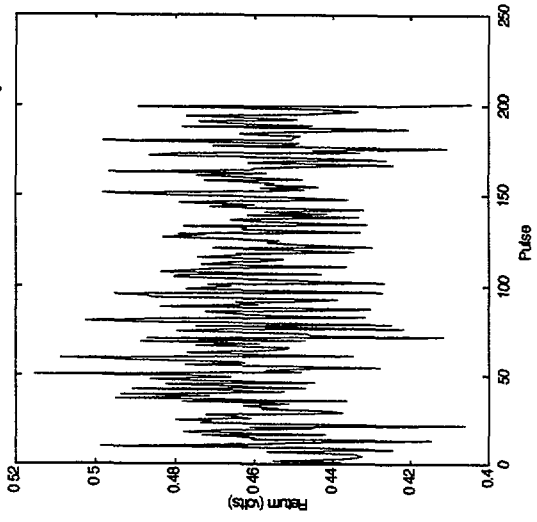
In orienting the radar with respect to a concealing material, care must be taken not to produce a significant direct reflection which may saturate the radar receiver and “blind” it to other objects. Also, and perhaps more serious from a threat assessment algorithm perspective, is the danger of having a concealing material generate numerous multipath returns. This could potentially place large burdens on the sensor processing electronics in terms of having to generate track files for objects which do not actually exist in the scene. Some level of multipath is inevitable just due to the complexity of the roadway environment, but inappropriately choosing and orienting a material in front of the radar sensor may severely compound the problem.

Another important issue regarding the attenuation characteristics of materials concerns accurately reporting range to roadway targets constructed from non-metal material. As vehicle manufacturers continue to reduce weights, the use of non-conductive plastic materials is expected to increase. As the results of these material tests indicate, use of non-conductive materials could severely decrease the overall radar cross-section of the vehicle.

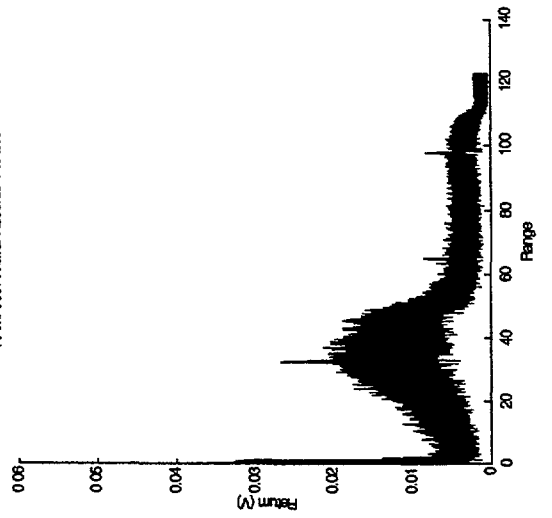
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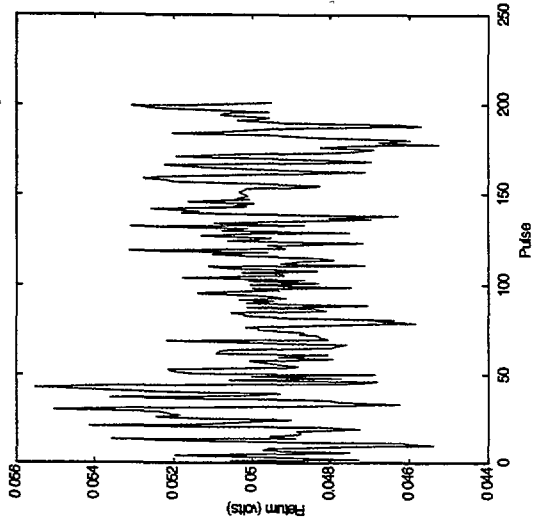
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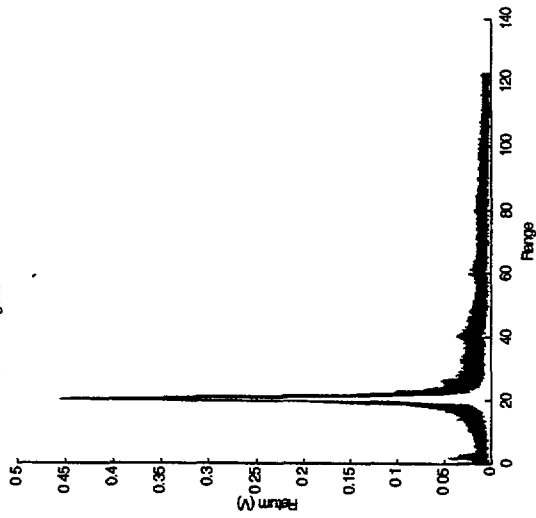
PAINT 960703b.rdf Records 1 to 200



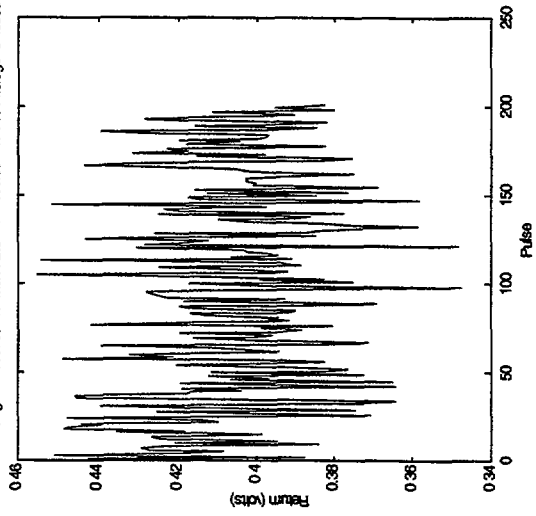
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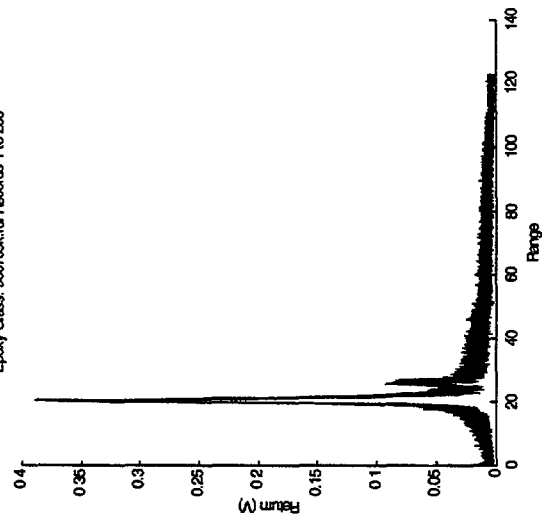
Clear Plexiglass: 960709d.tif Records 1 to 200



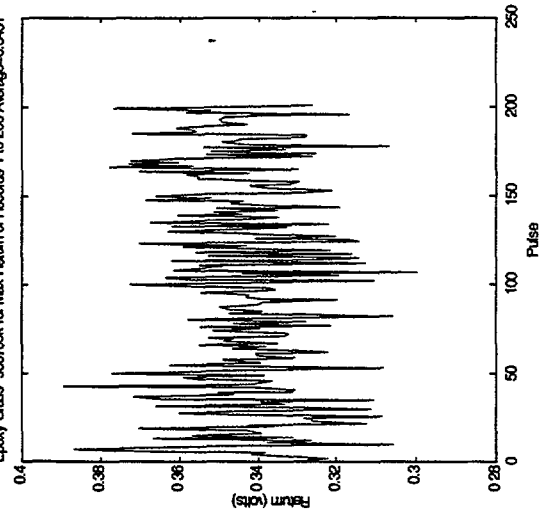
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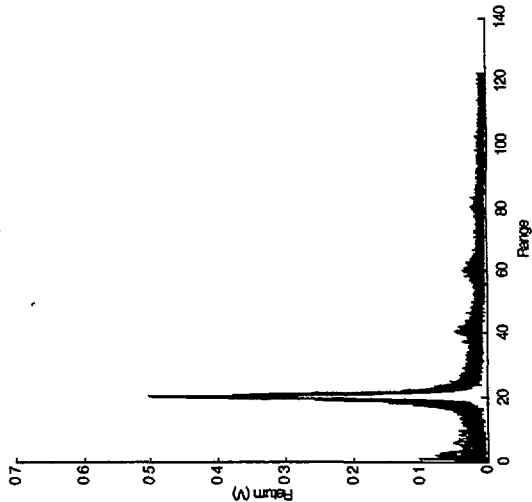
Epoxy Glass: 960709k.tif Records 1 to 200



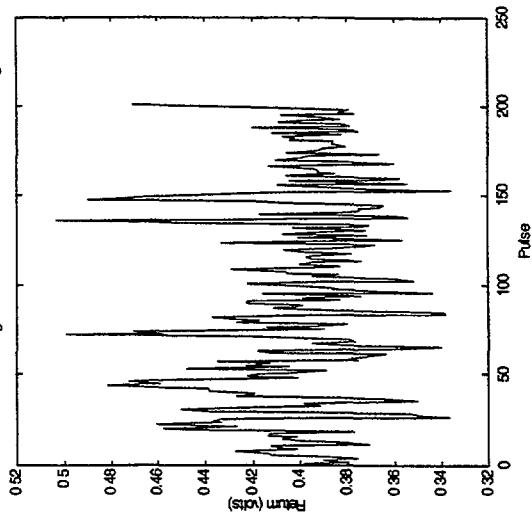
Epoxy Glass: 960709k.tif Max Return of Records 1 to 200 Average=0.3431



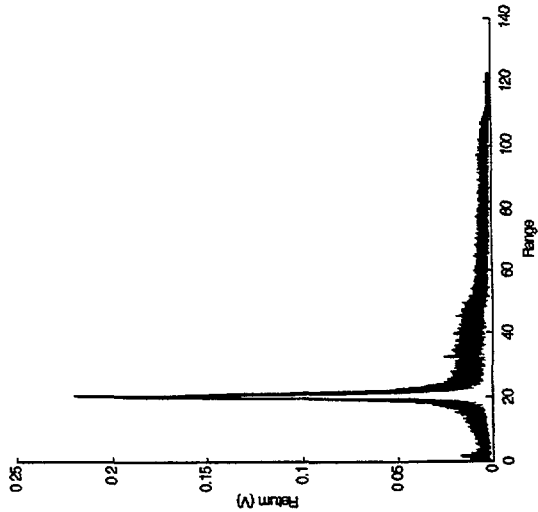
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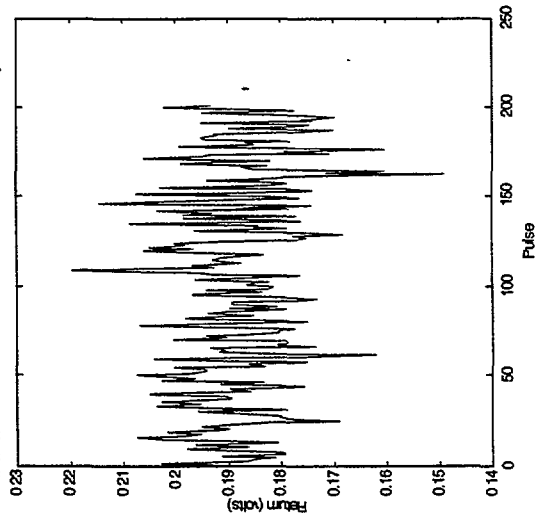
Thin Cardboard 960709g.rtf Max Return of Records 1 to 200 Average=0.40034



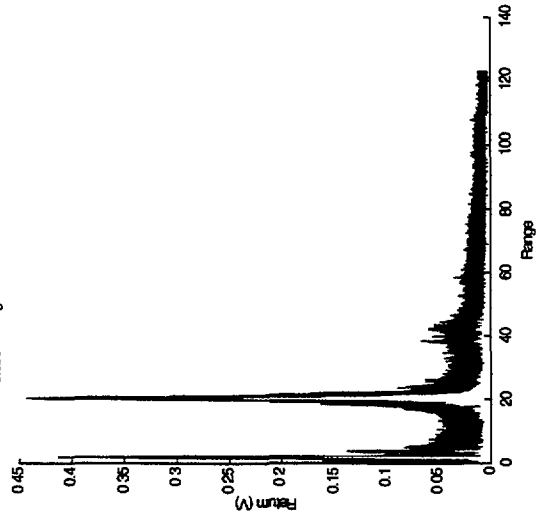
Thick Cardboard 960709h.rtf Records 1 to 200



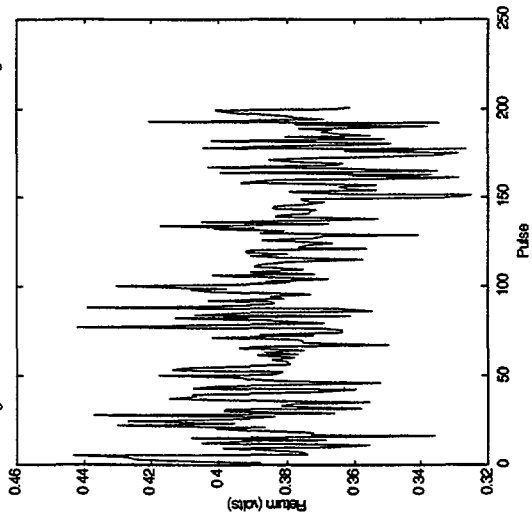
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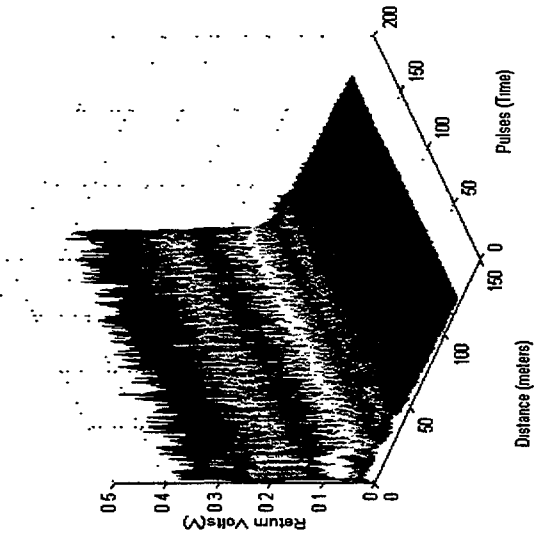
Glass 15 Degrees: 960709c.rdf Records 1 to 200



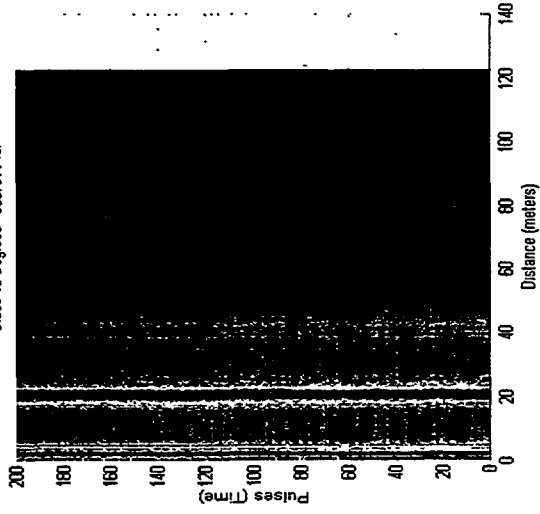
Glass 15 Degrees: 960709c.rdf Max Return of Records 1 to 200 Average=0.38094



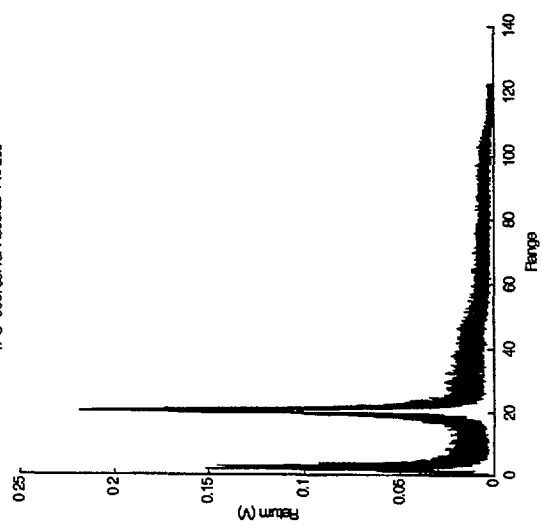
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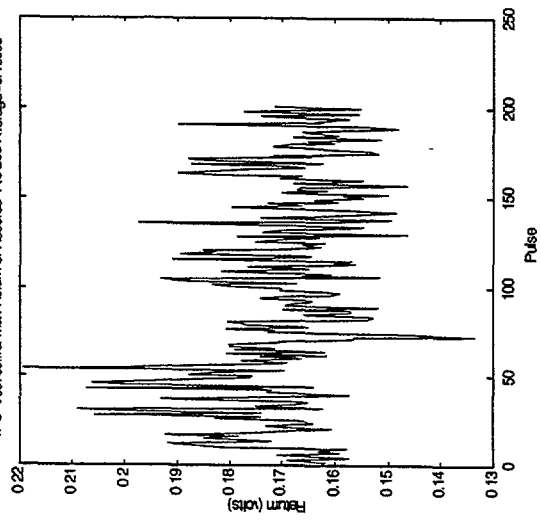
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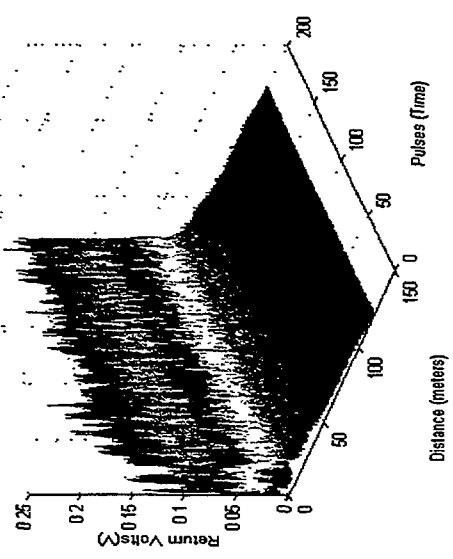
TPO-960709f.rdf Records 1 to 200



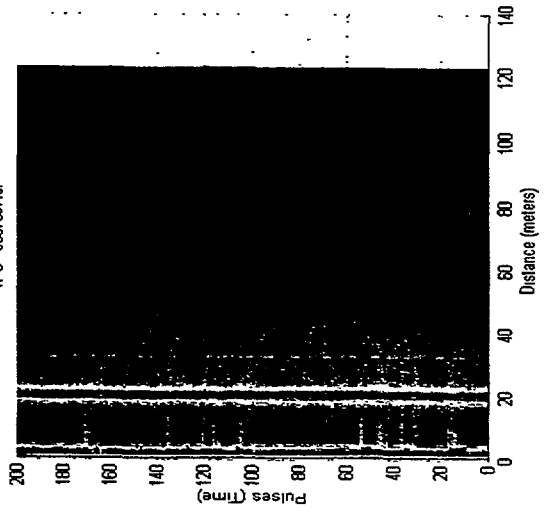
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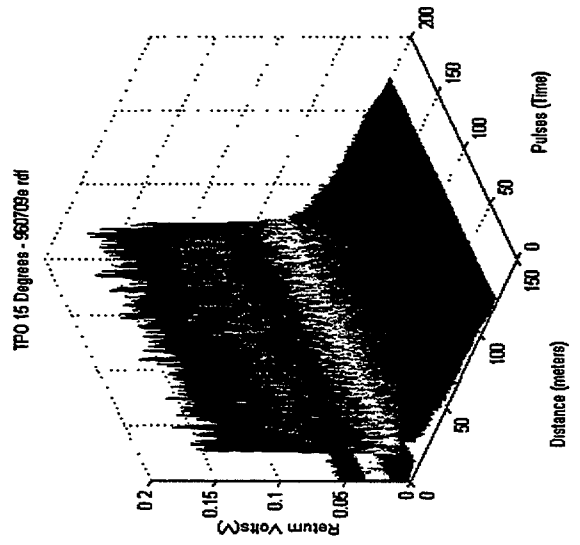
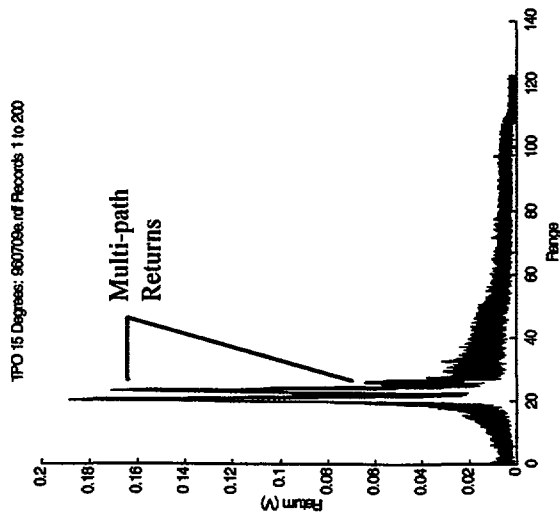
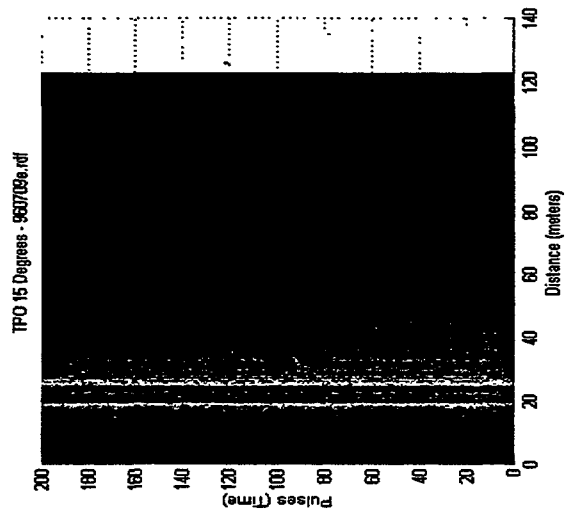
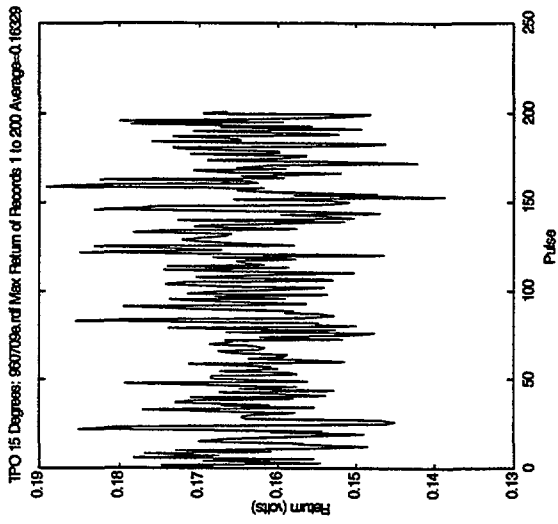


TPO-960709f.rdf

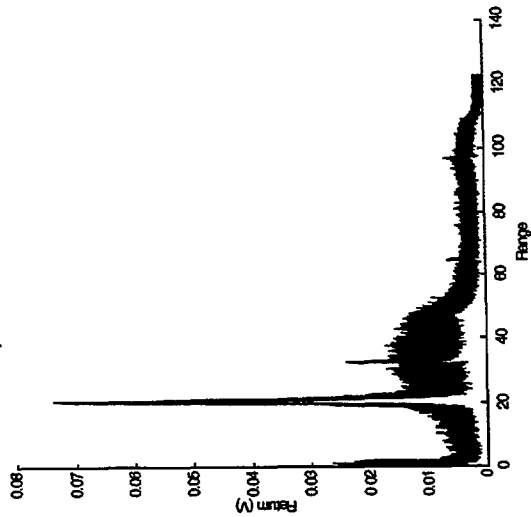


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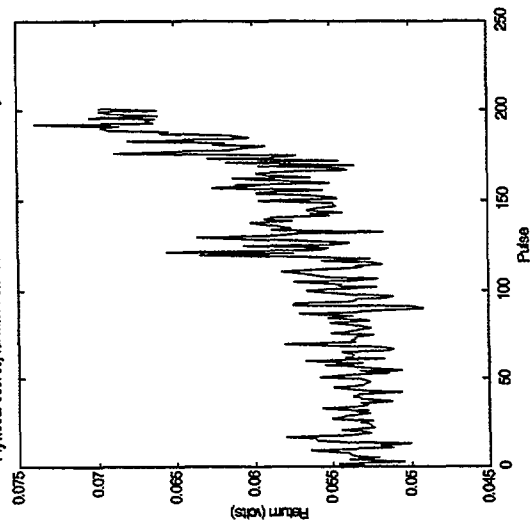




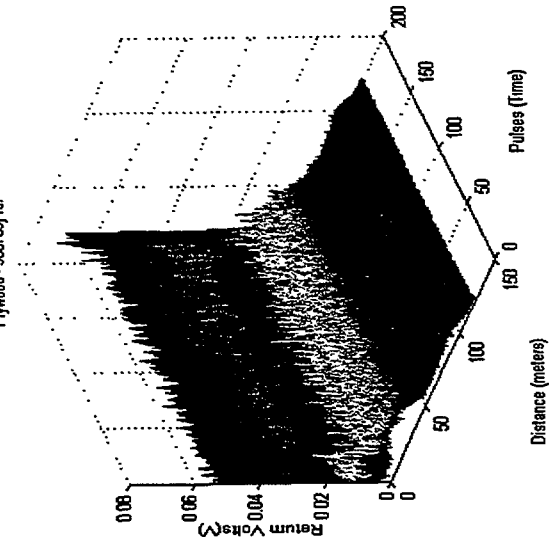
Plywood - 960703j rdf Records 1 to 200



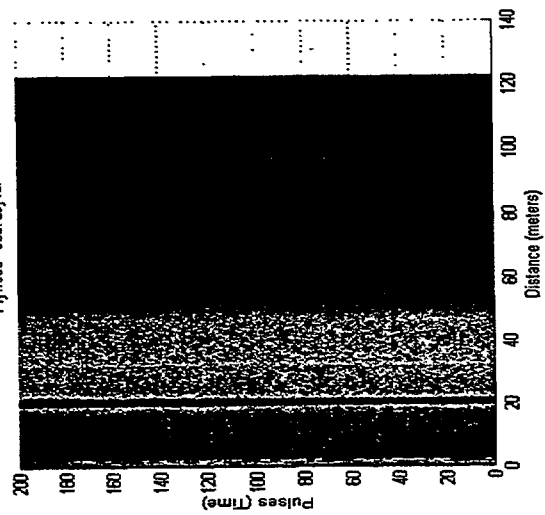
Plywood - 960703j rdf Max Return of Records 1 to 200 Average=0.069423



Plywood - 960703j rdf



Plywood - 960703j rdf



B.2 PRECIPITATION TESTS-SUMMARY

B.2.1 Purpose

The purpose of these precipitation tests was to evaluate the effects of snow, rain, and fog on the performance of the FLAR sensor.

B.2.2 Procedure

In general, the precipitation data collections were conducted as outlined below:

1. A reference target (either a vehicle or corner reflector) was placed within the FLAR's field-of-view at nominally a 10 to 20 meter range.
2. FLAR data was collected without any precipitation present, to provide a baseline for the specific collection.
3. Data was collected with varying degrees of precipitation rates present in the area between the FLAR and the target.
4. The data resulting from collections with precipitation present was compared to the baseline readings to determine the precipitation's effect on the performance. Return level averages and variances were used to quantify the effects.

Both natural and simulated precipitation tests were conducted to arrive at the results discussed below. The snow data was derived from natural snow precipitation only. The fog data was collected using an artificial fog machine. The rain data was collected using both natural rain and rain from a high-pressure washer to allow the precipitation rate to be more controlled.

B.2.3 Results

A set of representative plots summarizing the results of the tests are included at the end of this document. Note that data for these tests was collected during various periods and the results correlated fairly well from one collection scenario to another.

In general, the precipitation tested had little effect on the FLAR's performance. In particular, the precipitation particles were not found to produce any significant returns to the FLAR and the attenuation levels were very small.

Table B-2 shows the quantitative summary of the tests. The return levels and AGC settings for each collection are provided. These measured parameters were used to calculate the 'AGC adjusted voltage' values which are then compared to determine the attenuation levels. The "Baseline" for each collection was used as the reference for each attenuation calculation. Note that the attenuation levels provided are for "two-way" propagation. In other words, the radar signal passed through the precipitation-filled atmospheric medium twice--once on transmission, and once after it was reflected off of the target in the scene.

Table B-2. Precipitation Measurement

Precipitation Description	Target Range (m)	Measured Return Volts	AGC Control Setting (v)	AGC Mag. Attenuation (dB)	AGC Adjusted Return Volts	Two-Way Power Attenuation (dB)	Two-Way Power Attenuation (dB/10 m)
Light R a i n	13	0.492	3.906	-3.6324	0.6064	-0.4	-0.29
Moderate Rain	13	0.441	3.906	-3.6324	0.5436	0.6	0.44
Heavy Rain	13	0.421	3.906	-3.6324	0.5189	1.0	0.75
Moderate Snow	22	0.083	3.906	-3.6324	0.1023	-0.7	-0.30
Heavy Snow	22	0.085	3.906	-3.6324	0.1048	-0.9	-0.39
Fog l	3	0.366	3.906	-3.6324	0.4511	0.3	1.05
Fog 2	3	0.375	3.906	-3.6324	0.4622	0.1	0.35

Figure B-10 illustrates the attenuation levels produced from the various levels and types of precipitation. These attenuation levels have been normalized to 10 meter ranges. These values are considered insignificant since return levels from the FLAR during static collections with precision reference reflectors in a controlled environment have been observed to fluctuate by values similar to these. Note that negative attenuation levels indicate that the peak return from the target in the scene actually increased. This could potentially be due to the target getting wet and causing more of the radar energy to be directed back in the direction of the FLAR or due to the ground between the radar and the target getting wet and causing a higher level of multipath return.

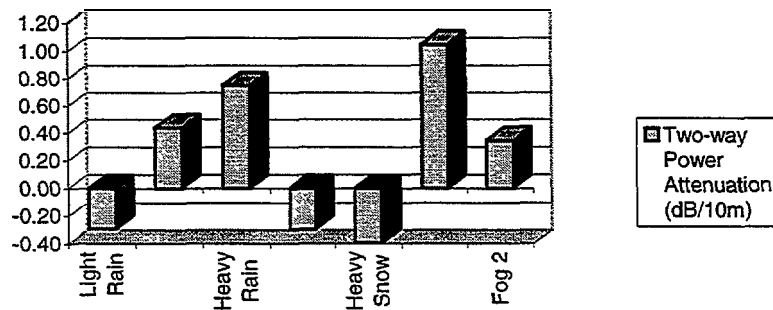


Figure B-10. Two-Way Power Attenuation (dB/10 m)

B.2.4 Conclusions

The primary conclusion of this test is that the FLAR performance was not observed to be significantly affected by the various levels and types of precipitation tested. In particular, the precipitation did not produce any observable return levels in the FLAR IF signal, and the attenuation levels were very low. However, the combination of a low RCS target at a far range during heavy rates of precipitation (or heavy fog) could cause a problem for an automotive radar.

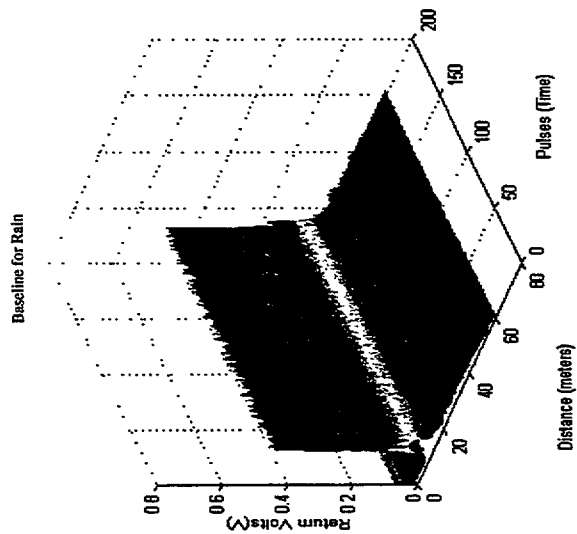
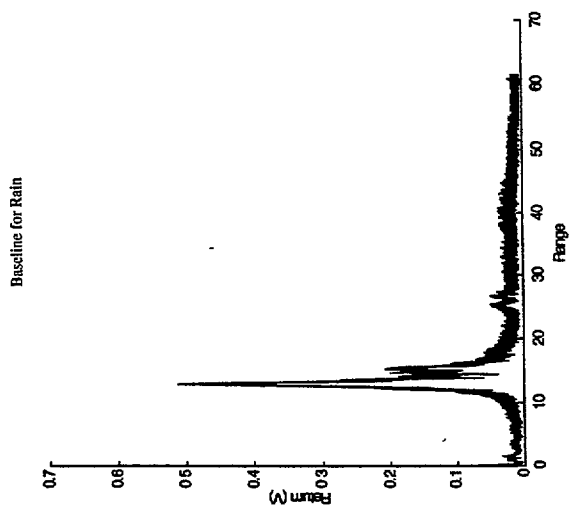
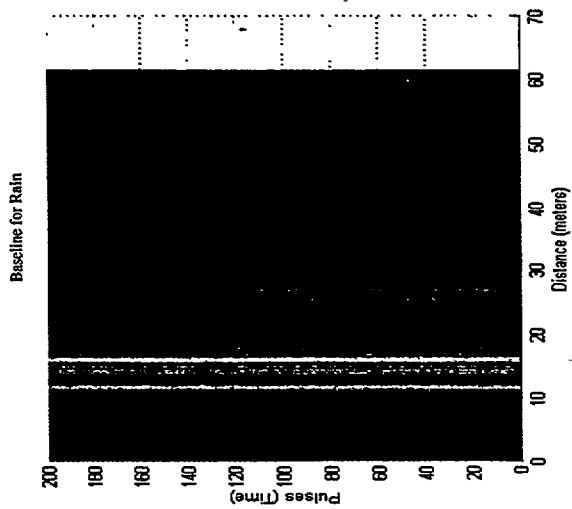
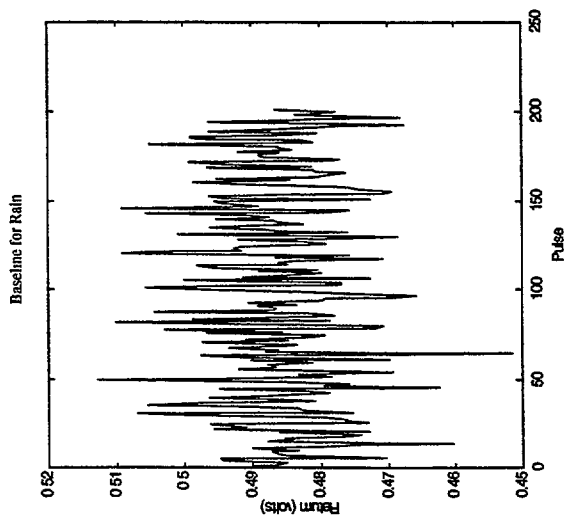
The results achieved during this testing correlate well with those in the open literature. There are several papers which have been published on the attenuation of high frequency communication systems as a result of precipitation. In general, both theoretical and empirical attenuation levels -are stated to be about 10 dB per kilometer (one-way). Relating the information obtained in the open literature to the operating ranges for automotive radars, one could expect power attenuation levels on the order of 1 to 3 dB at 100 meter ranges.

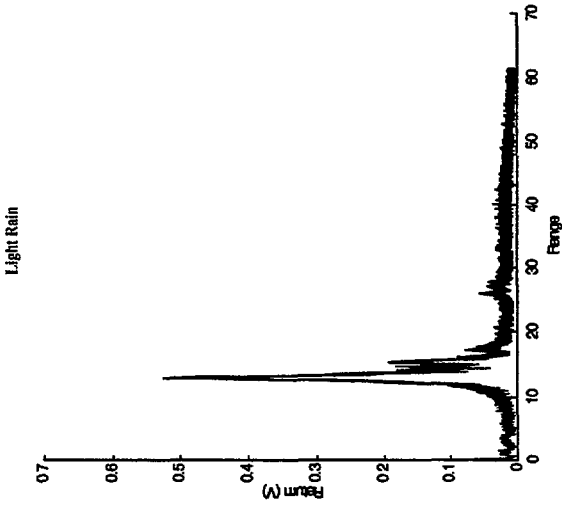
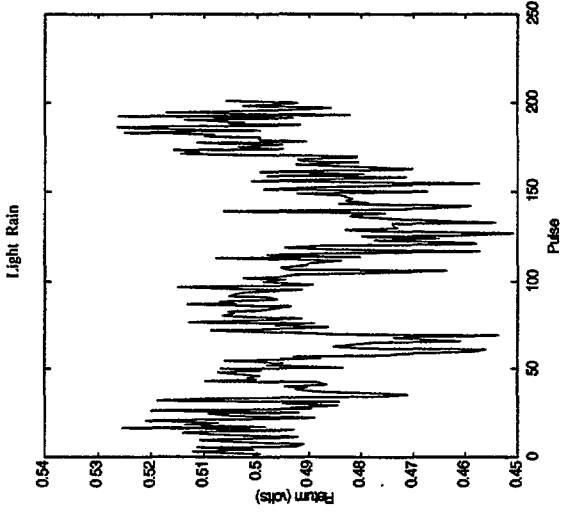
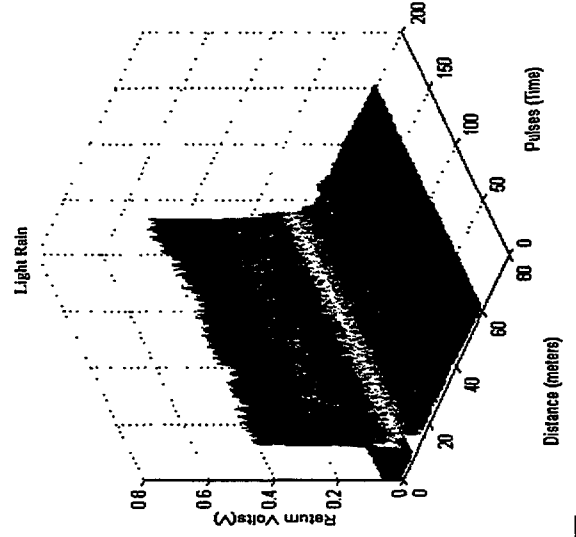
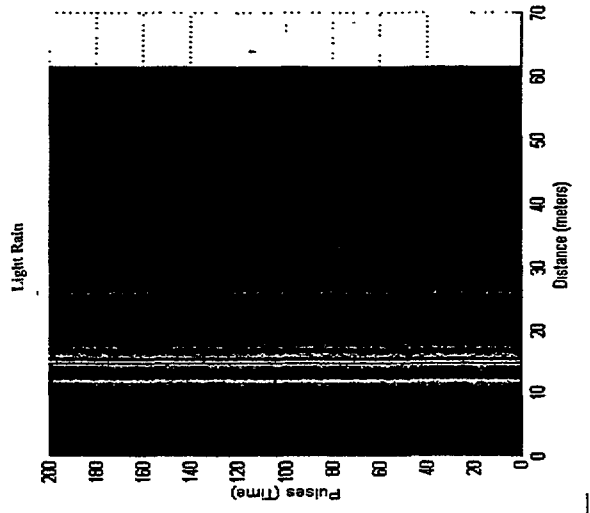
The measurements conducted as part of this program indicate that the actual attenuation levels may be somewhat higher than the 1 to 3 dB values mentioned above. More practical values could range from 2 to 10 dB of power loss at 100 meter ranges. Of course these values are highly dependent upon the rate of precipitation and also the particulate size of the precipitation. As the particulate size approaches $\pi/4$ wavelength of the radar frequency, the particulate will begin acting as an antenna.

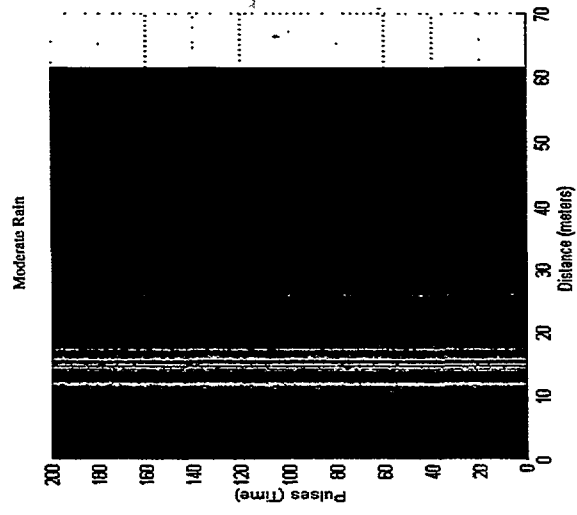
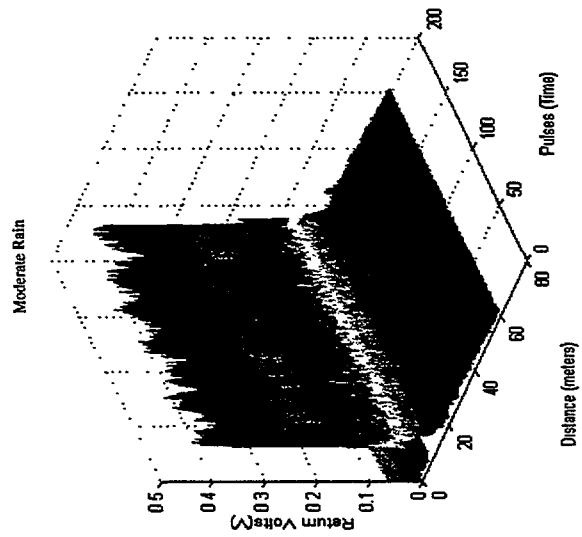
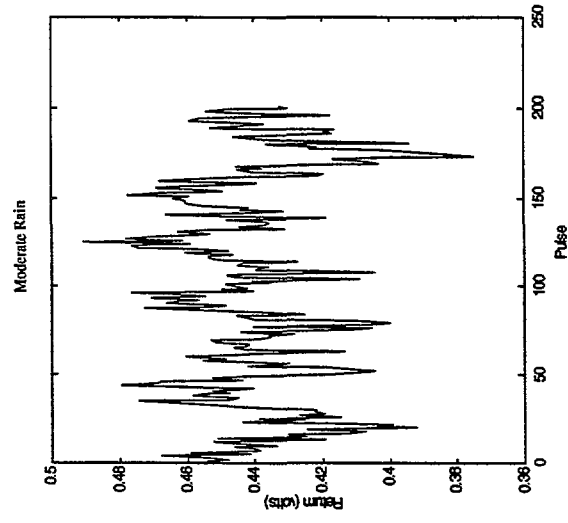
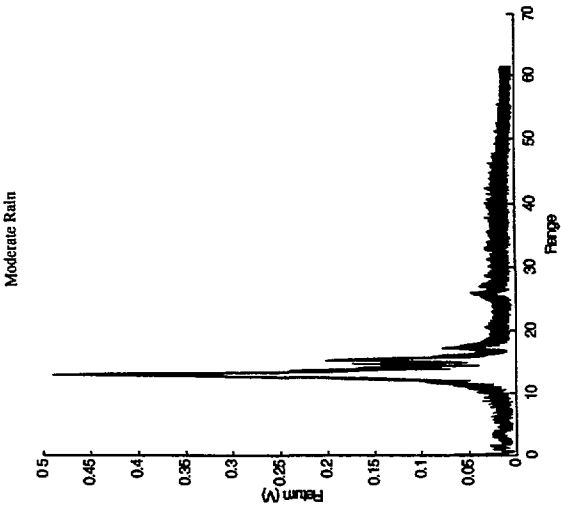
In practical terms, the most important outcome of this test was the verification that the FLAR was capable of detecting targets within its field-of-view in the presence of significant precipitation. Except for the light rain collections, the target itself was visually obscured from the FLAR's location. During the heavy rain and fog tests, the target was frequently totally visually obscured. Despite the visual obscuration, return levels from the target were easily observed in the raw radar signal. These observations provide empirical support to those who cite radar's all-weather performance advantage over infra-red or optical sensors for automotive applications.

The surprising phenomenon observed during the testing was the occasional increase in return levels in the presence of precipitation. This was observed during several collections. While the increase was not significant, it was measurable. Possible explanations for this phenomena are:

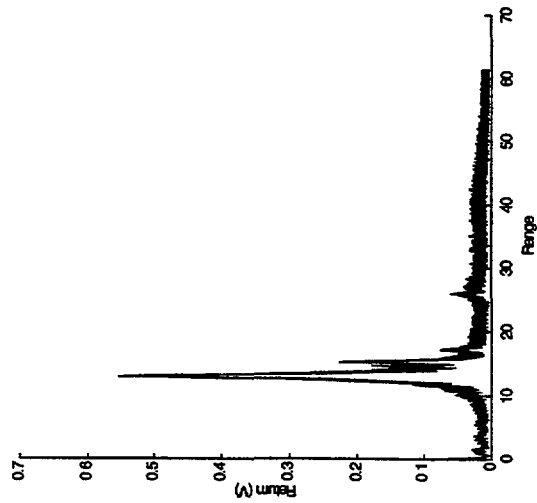
- As the precipitation fell, the ground between the radar and the target became wet and caused a larger multipath return to be produced. Theoretically, enhanced multipath returns can increase actual target returns over 10 dB given a particular geometry.
- As the precipitation particles landed in the target, they caused an increase in the non-specular returns due to increased refraction and energy scattering. For tests conducted with reference reflectors, the increase may have come from particles landing on the Styrofoam support pedestal.



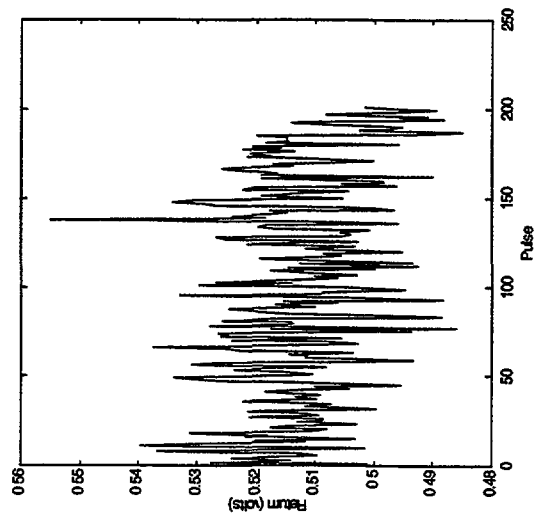




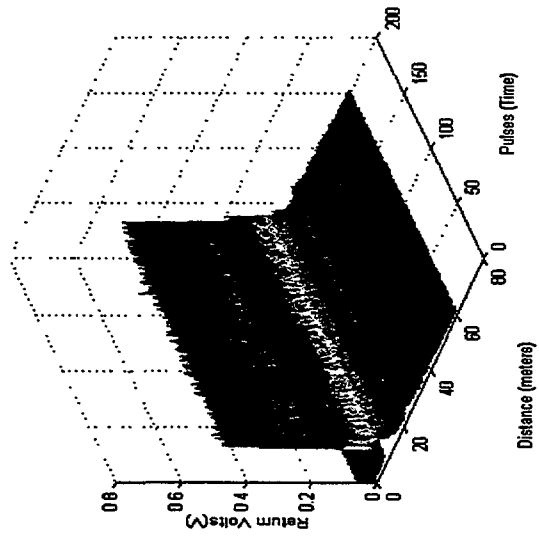
Sheet of Rain



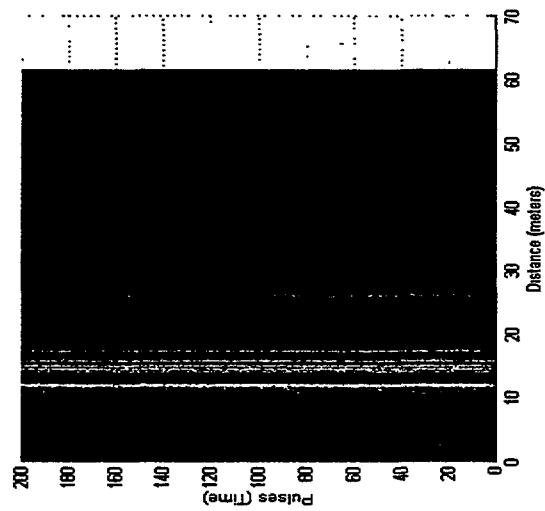
Sheet of Rain

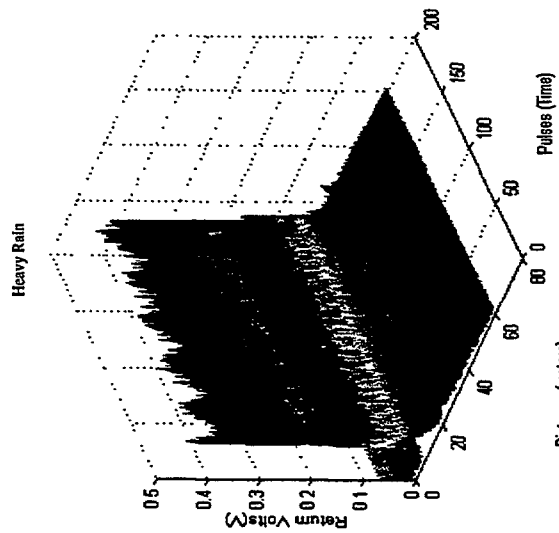
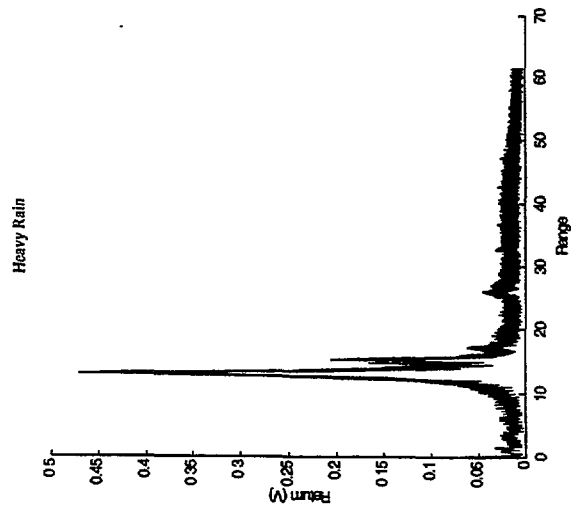
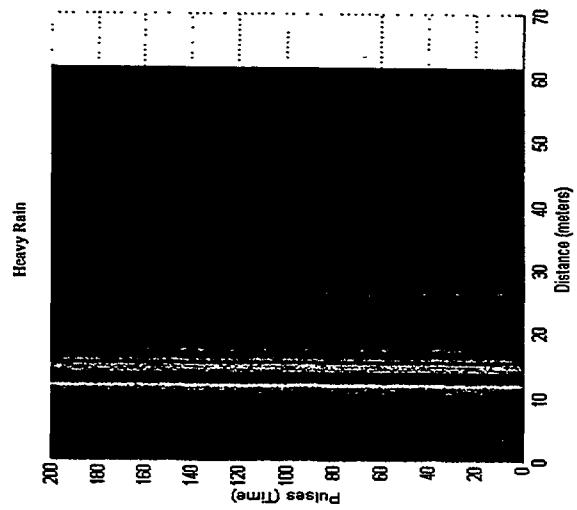
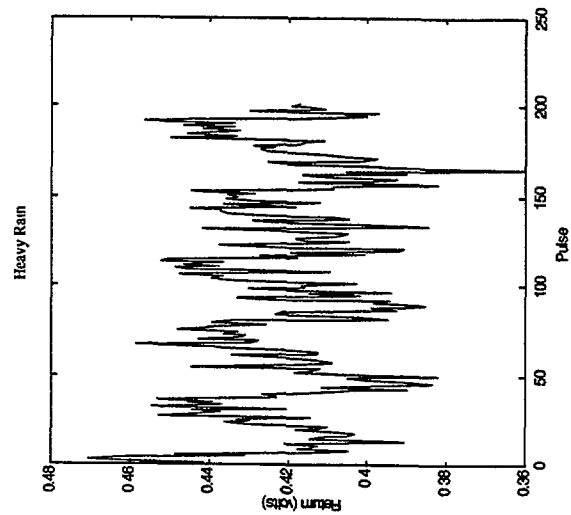


Sheet of Rain

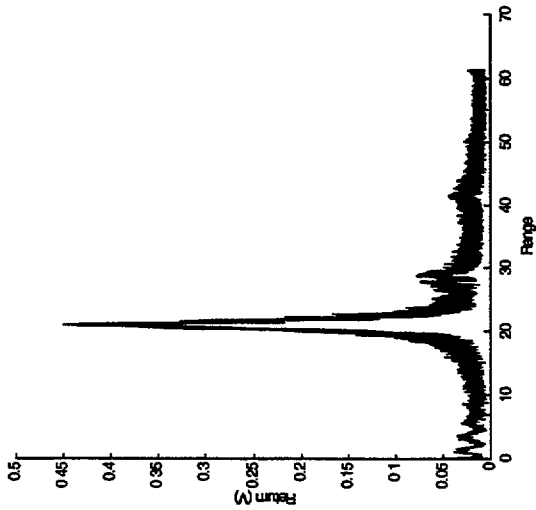


Sheet of Rain

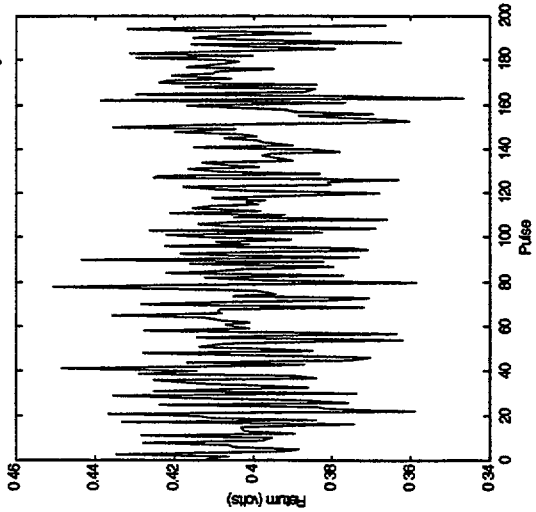




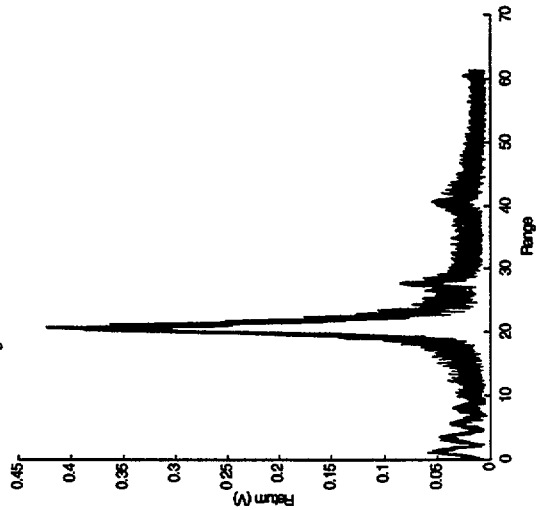
Baseline for Snow: 970127b.rtf Records 1 to 195



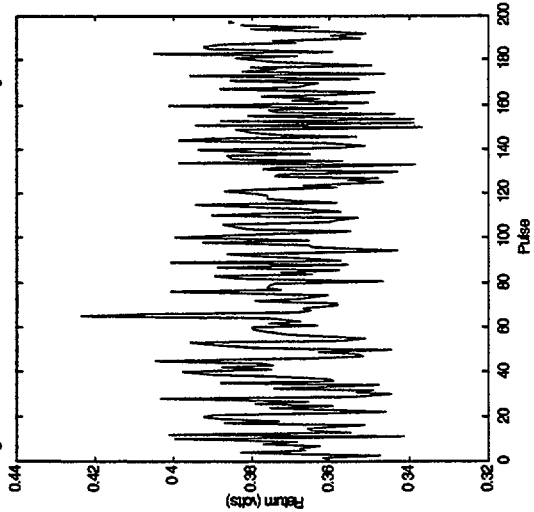
Baseline for Snow: 970127b.rtf Max Return of Records 1 to 195 Average=0.40146



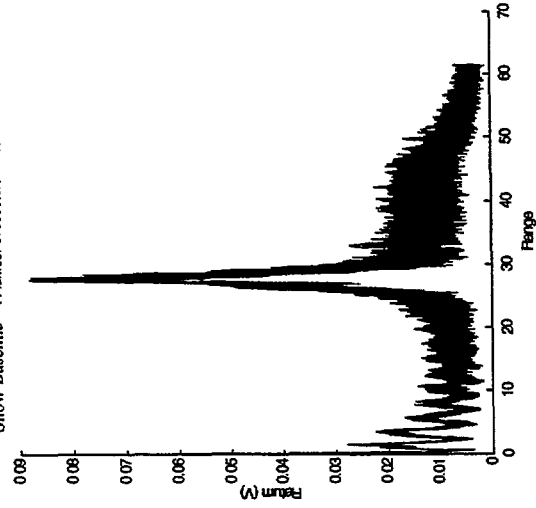
Light Snow: 970127c.rtf Records 1 to 195



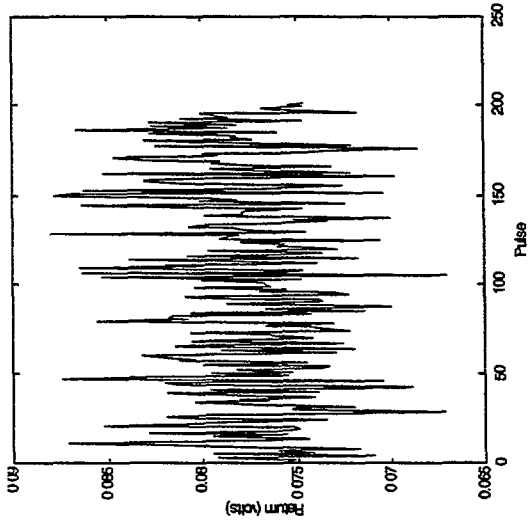
Light Snow: 970127c.rtf Max Return of Records 1 to 195 Average=0.37098



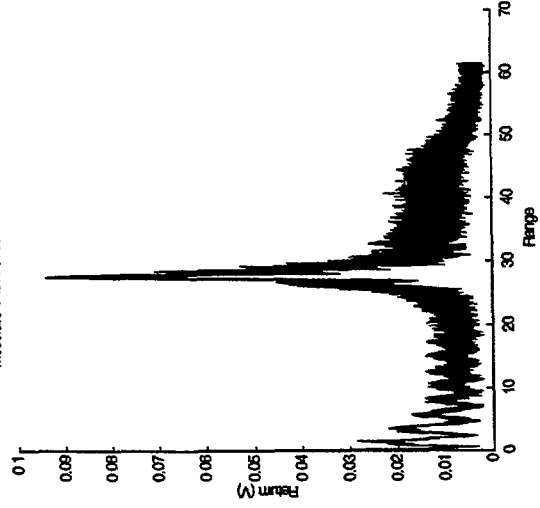
Snow Baseline 1 Flurist: 970306a.rtf Records 1 to 200



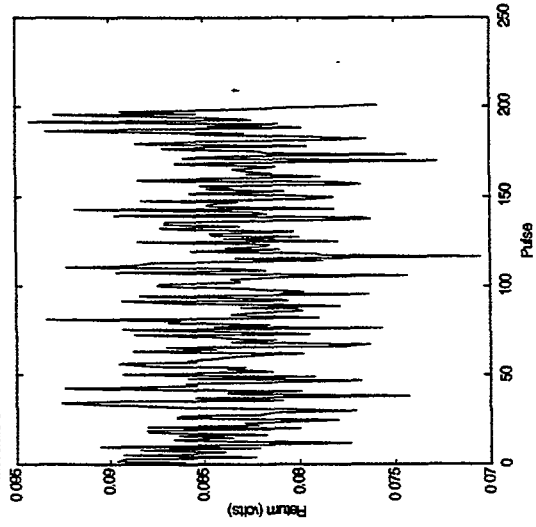
Snow Baseline : 970306a.rtf Max Return of Records 1 to 200 Average=0.077594



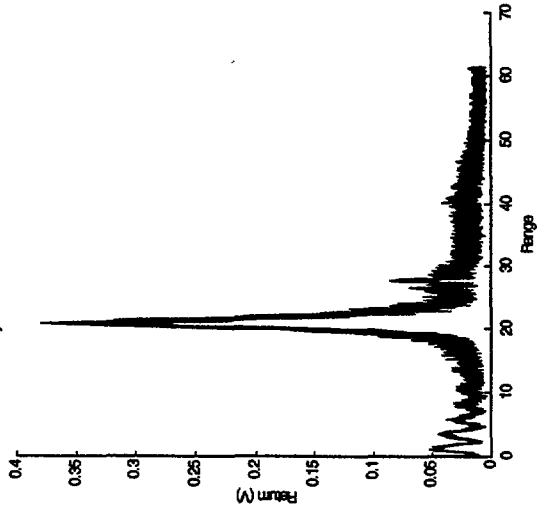
Moderate Snow: 970306b.rtf Records 1 to 200



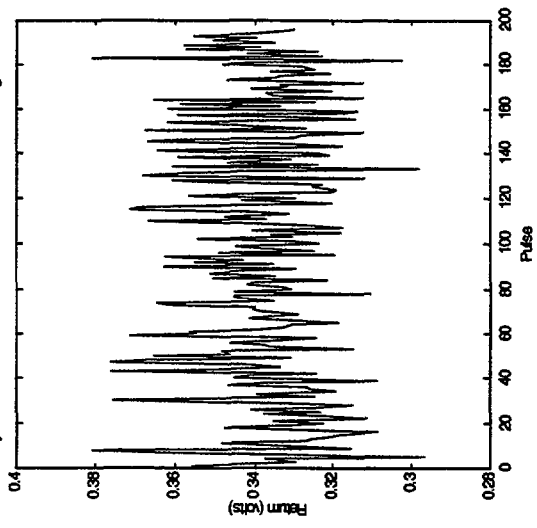
Moderate Snow: 970306b.rtf Max Return of Records 1 to 200 Average=0.083526

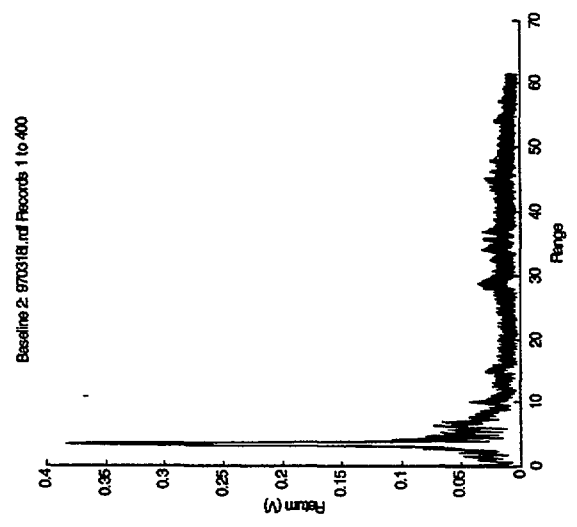
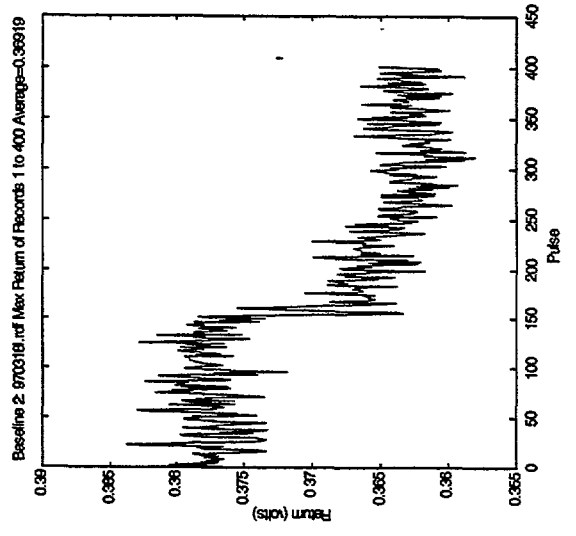


Heavy Snow: 870127d.rtf Records 1 to 195

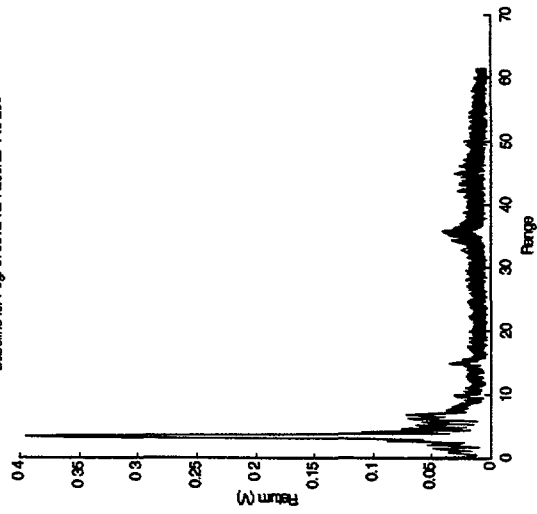


Heavy Snow: 870127d.rtf Max Return of Records 1 to 195 Average=0.33818

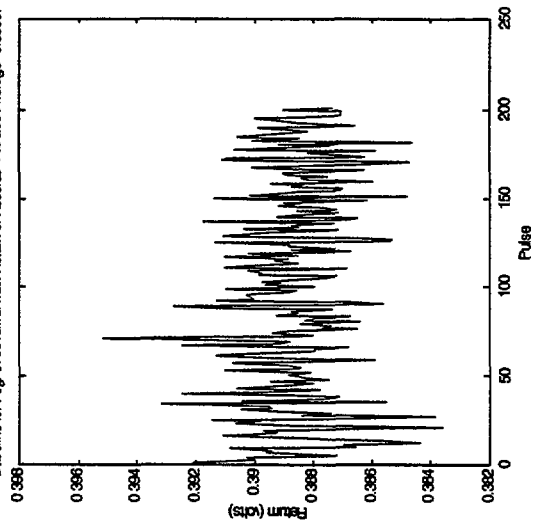




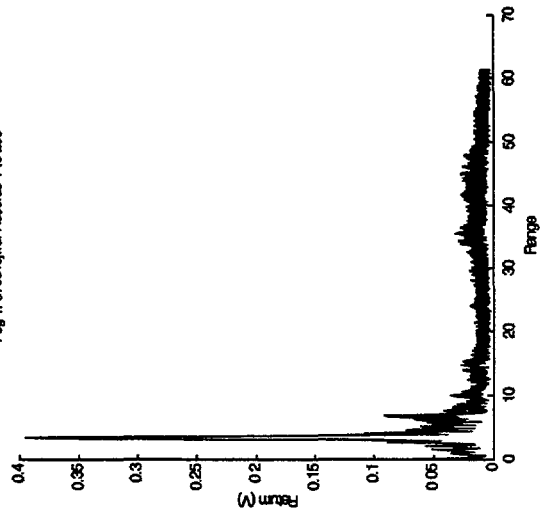
Baseline for Fog 970318I rd Max Return of Records 1 to 200



Baseline for Fog 970318I rd Max Return of Records 1 to 200 Average=0.36687



Fog 1: 970318I rd Max Return of Records 1 to 200



Fog 1: 970318I rd Max Return of Records 1 to 200 Average=0.36621

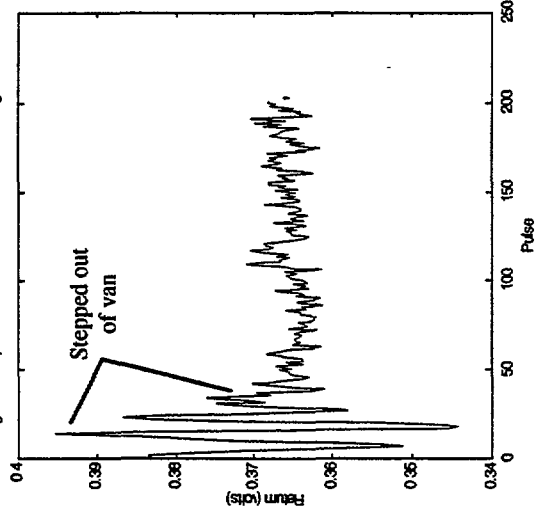


Fig 2: 970318k.raif Records 1 to 500

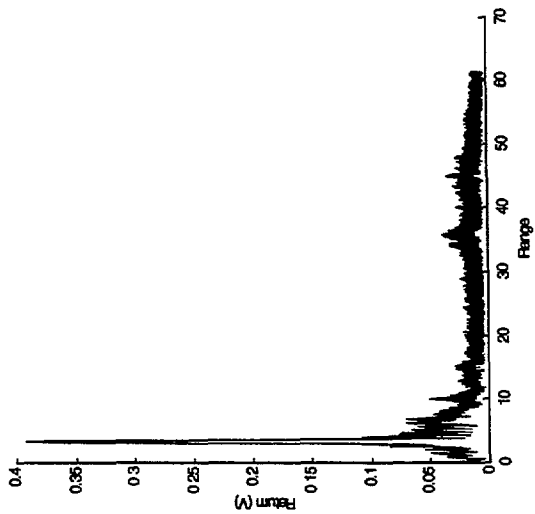
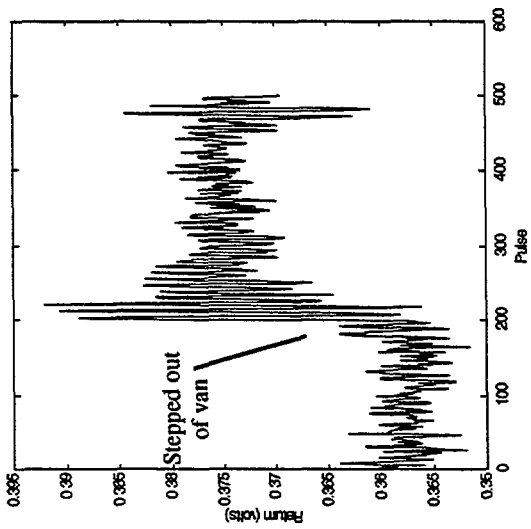


Fig 2: 970318k.raif Max Return of Records 1 to 500 Avg(records 200:600)=0.37483



B.3 CONTAMINATION TESTS—SUMMARY

B.3.1 Purpose

The purpose of these contamination tests was to evaluate how dirt, moisture, and snow would effect the FLAR's performance. The "contamination" could occur either at the target location or at the sensor. For example, the target itself would be considered "contaminated" if it were snow covered, or the sensor could be "contaminated" if its antenna's were covered with mud.

B.3.2 Procedure

In general, the contamination data collections were conducted as outlined below:

1. A reference target (either a vehicle or corner reflector) was placed within the FLAR's field-of-view at nominally a 10 to 30 meter range.
2. FLAR data was collected without any contamination present, to provide a baseline for the specific collection.
3. The contaminating material was applied to either the target or the sensor. (Note that in the case of applying the contamination to the sensor, a glass plate was placed in front of the sensor during the baseline tests, and then the contaminate was actually applied to the glass plate. This was to simulate having the contaminate on the radome of the FLAR.)
4. FLAR data was collected with the contamination present.
5. The data resulting from collections with the contamination present was compared to the baseline readings to determine performance effects on the FLAR due to the contamination. Return level averages and variances were used to quantify the effects.

The following contamination scenarios were tested:

- Vehicle target contaminated with snow: In this scenario, the rear portion of the target vehicle (a Pontiac Sunbird) was partially (about 50 percent) with fairly dry snow.
- Vehicle target contaminated with water: In this scenario, the target vehicle (a small pick-up truck) was sprayed with water from a hose. Care was taken to perform the baseline test with already wet ground to isolate the vehicle contamination from multipath effects.
- FLAR sensor contaminated with snow: This scenario had approximately 1 inch of snow densely packed on the face of the FLAR sensor.
- FLAR sensor contaminated with semi-dry mud: The mud tests were divided into two levels of contamination. The first level had the glass plate covered with mud, but still visually translucent. The second level had the glass plate covered with thick so that it was visually opaque. This second level is referred to in the tests as "very muddy."

B.3.3 Results

A set of representative data plots summarizing the results of the tests are included at the end of this document.

The results of the contamination tests were not what was intuitively expected. Therefore, several data sets were collected/analyzed for each type of test and the results were found to be consistent.

Table B-3 shows the quantitative summary of the tests. The return levels and AGC settings for each collection are provided. These measured parameters were used to calculate the "AGC adjusted voltage"

values which are then compared to determine the attenuation levels. The “Baseline” for each collection was used as the reference for each attenuation calculation. Note that the attenuation levels provided are for “two-way” propagation.

Table B-3. Contamination Measurement

Material Description	Measured Return Volts	AGC Control Setting (v)	AGC Mag. Attenuation (dB)	AGC Adjusted Return Volts	Two-Way Power Attenuation (dB)
Water on Truck	0.514	3.906	-3.632	0.634	-0.5
Snow on Car	0.09	3.906	-3.632	0.111	-1.2
Translucent Mud at Sensor	0.197	3.906	-3.632	0.243	-0.7
Opaque Mud at Sensor	0.306	3.906	-3.632	0.377	-4.5
Snow Covered Sensor	0.02	3.906	-3.632	0.025	11.8

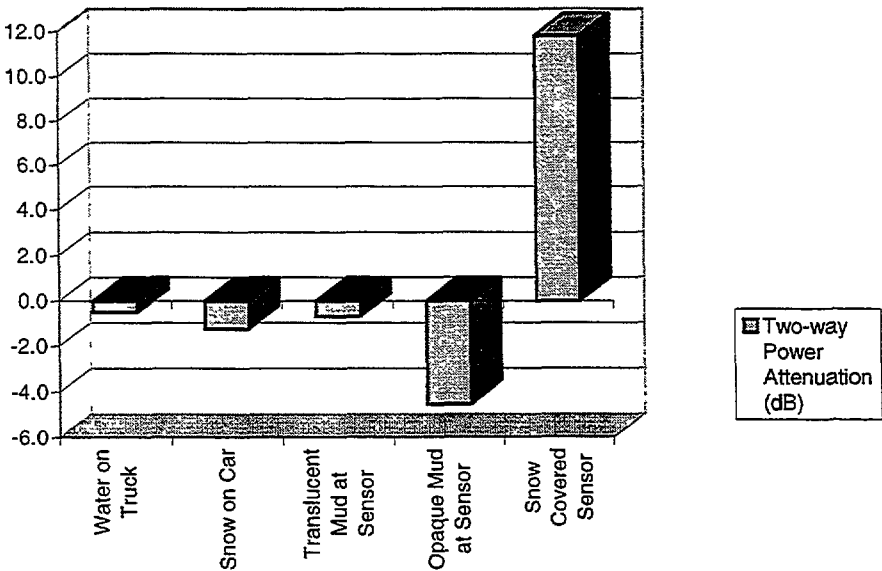


Figure B-11. Two-Way Power Attenuation (dB)

Figure B-11 above illustrates the attenuation levels produced from the various types of contamination. Note that negative attenuation levels indicate that the peak return from the target in the scene actually increased.

The contaminated vehicle test results correlate with some of the observations made during the precipitation tests. In these cases, a potential explanation is that the particulate contamination on the vehicle may be enhancing the return level by creating more scattering centers through refraction of the radar energy. Figure B-12 illustrates this concept.

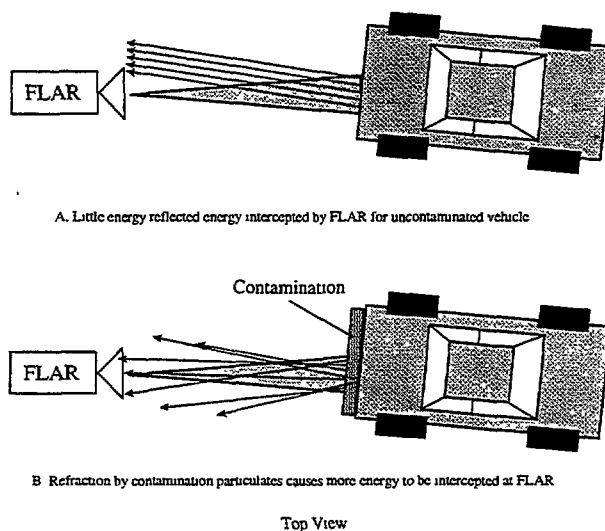


Figure B-12. Potential Cause for Contaminated Target Increased RCS

Figure B-12 shows how a contamination layer might cause reflected energy to become more diffused compared to the reflections from an uncontaminated target. While this diffusion process may cause the power density (mW/cm^2) of the reflected wave to decrease, the FLAR still intercepts more power per unit area (i.e., the receive antenna aperture). Note that this explanation is a hypothesis which should be verified through further testing which was beyond the scope of this project.

Similar to the contaminated target results were the results from the contaminated sensor testing using semi-dry mud. These tests again resulted in 'negative' attenuation, or an observed gain in peak return level. In analyzing the range profiles for the mud contamination tests, it was observed that the contaminated glass plate itself did NOT reflect energy back to the FLAR. The only difference between the baseline and contamination tests was the peak return level from the reference reflector. A potential cause for this phenomena could be an effect similar to that described above, except that the diffusion of energy occurs at the contaminated glass plate (approximately 1 meter in front of the sensor) rather than at the target. Again, this explanation is a theory requiring more stringent contamination testing for verification.

Finally, the result of the contamination test in which the FLAR sensor "caked" with 1 inch of wet snow indicates that the snow inhibited the sensor from detecting the reference target. Note that the 11 dB signal attenuation caused the reference target return to drop below the system noise level.

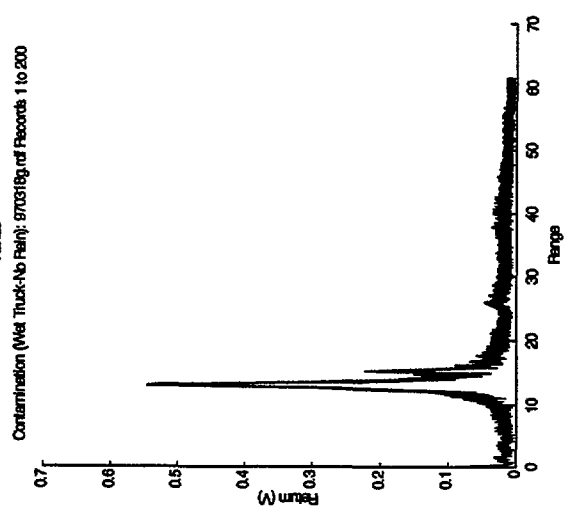
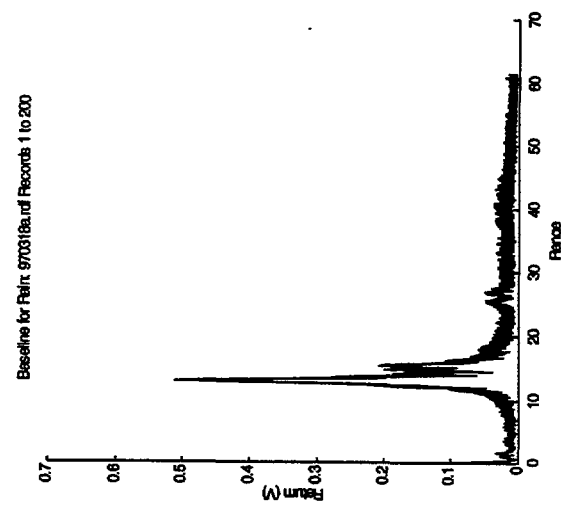
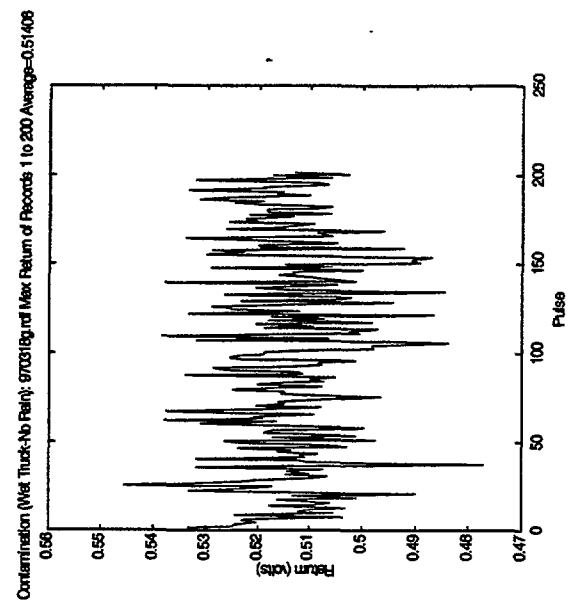
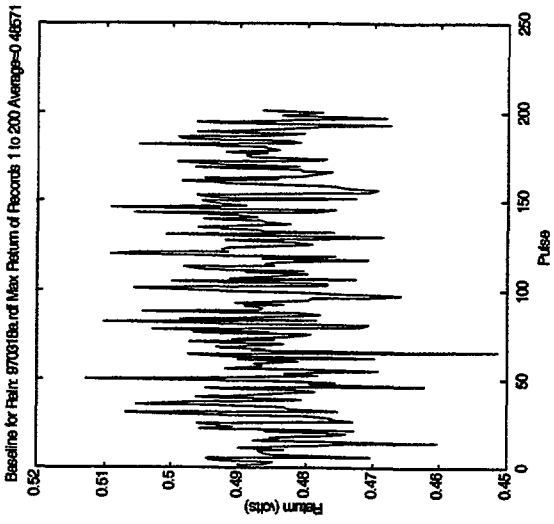
B.3.4 Conclusions

The analysis of the contamination tests have identified some phenomena which were unanticipated. The presence of contamination particulates at both the target and sensor have been observed to cause an increase in the peak return from reference targets in the FLAR's field of view. A potential mechanism for creating this phenomena is presented in the discussion of the test results given above. **It should be noted that this hypothesis has not been thoroughly tested and more research into the phenomena is required.** While the measurement equipment and procedures have been reviewed, the limited access to the FLAR electronics has severely limited the ability to rule a sensor specific response to the contamination scenarios which may be causing the unanticipated observations.

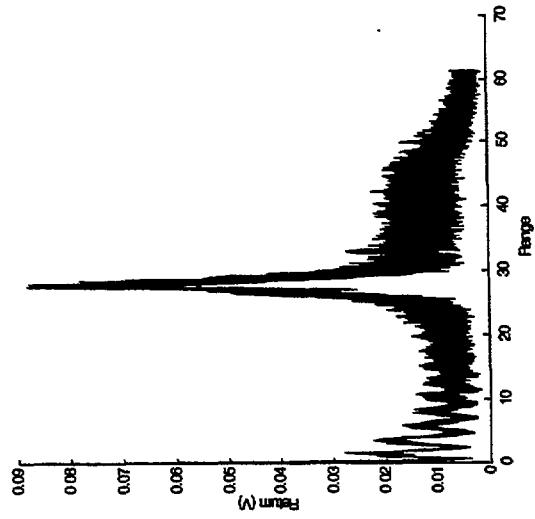
Notwithstanding the explanation for the observed phenomena, the primary conclusion from these tests is that both target and sensor contamination from rain, snow, and mud may cause return levels from targets in the scene to actually increase. This would of course add to the robustness of the automotive

radar in detecting objects at non-specular aspect angles, however, the mechanism causing this phenomena needs to be more clearly understood.

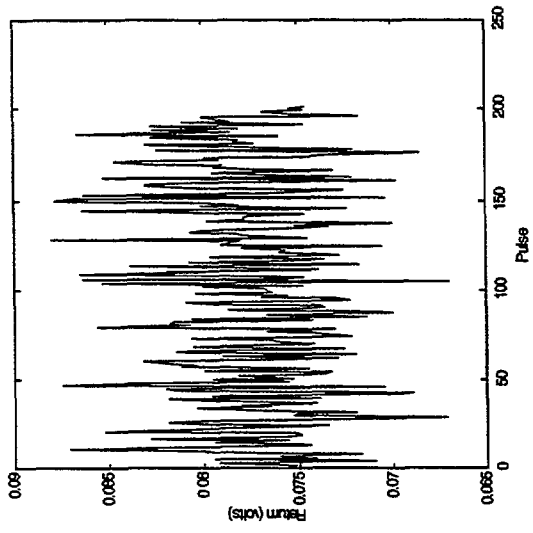
Conversely, the snow-covered sensor tests indicate that certain contaminants could cause severe degradation in sensor performance to the point of missing significant targets within the scene.



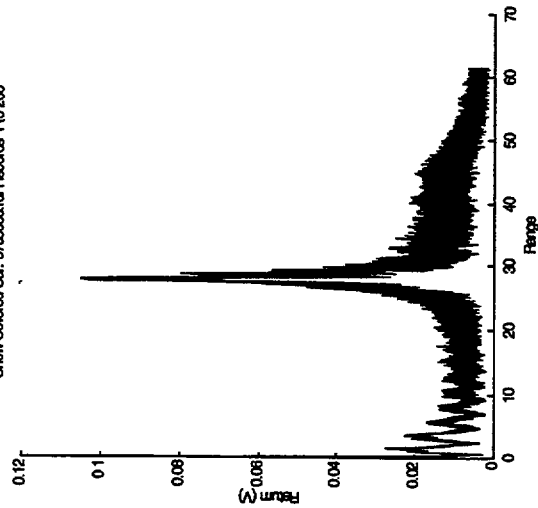
Snow Contamination Baseline 970306a.rtf Records 1 to 200



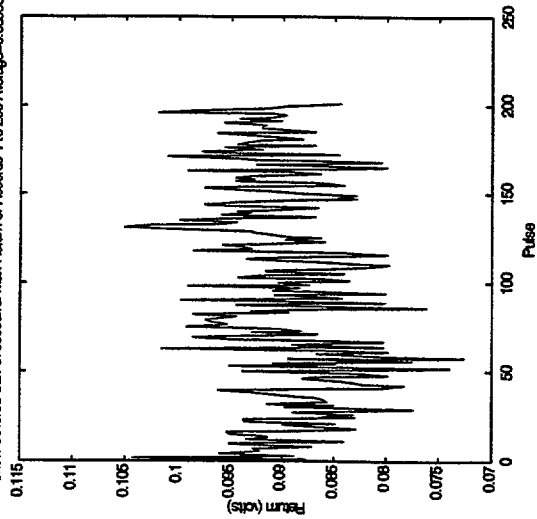
Snow Contamination Baseline 970306a.rtf Max Return of Records 1 to 200 Average=0.077684



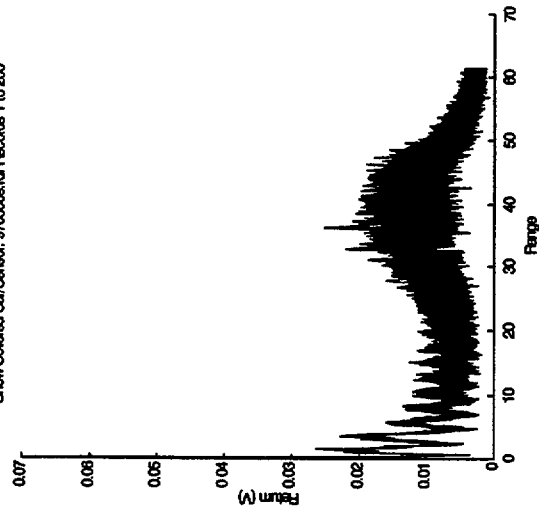
Snow Covered Car: 970306d.rtf Records 1 to 200



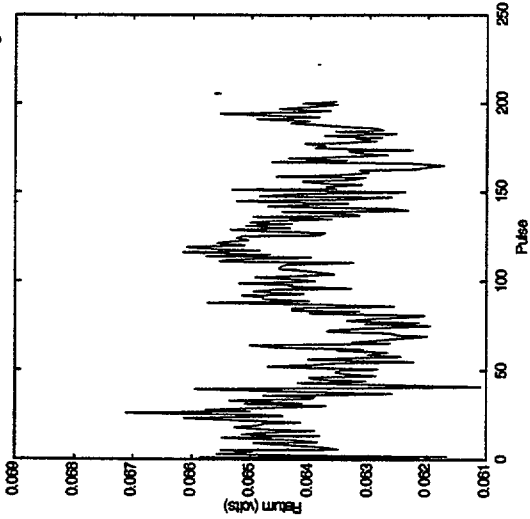
Snow Covered Car: 970306d.rtf Max Return of Records 1 to 200 Average=0.089997



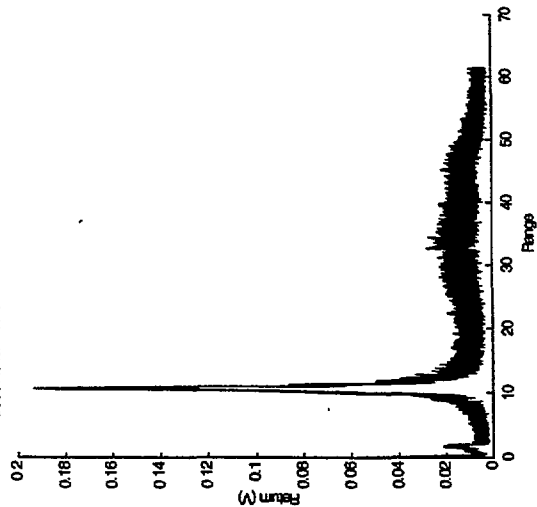
Snow Covered Car/Sensor: 970306a.rtf Records 1 to 200



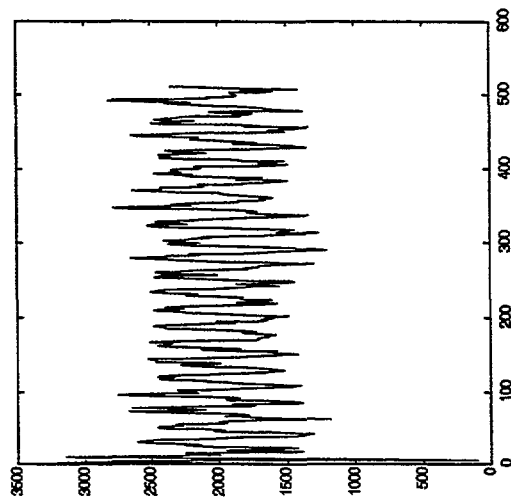
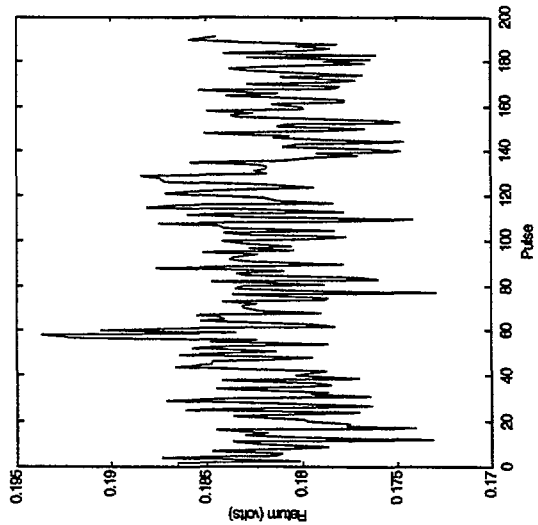
Snow Covered Car/Sensor: 970306a.rtf Max Return of Records 1 to 200 Average=0.063972



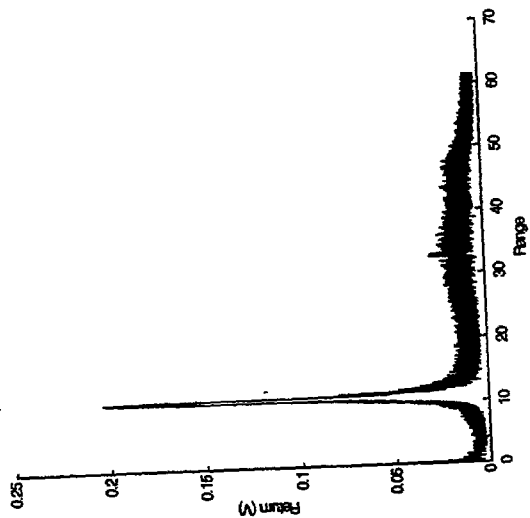
Baseline for Mud Contamination: 9603131.rtf Records 1 to 190



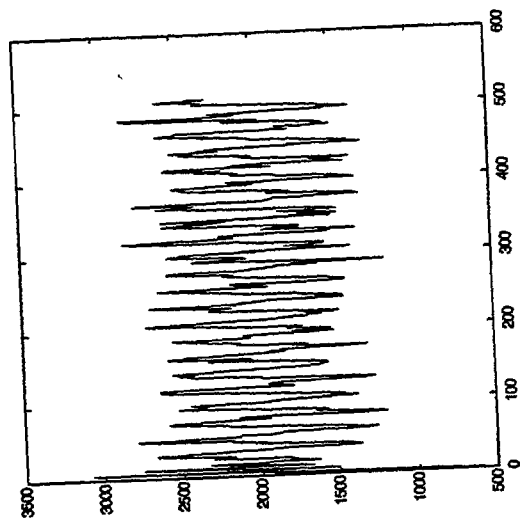
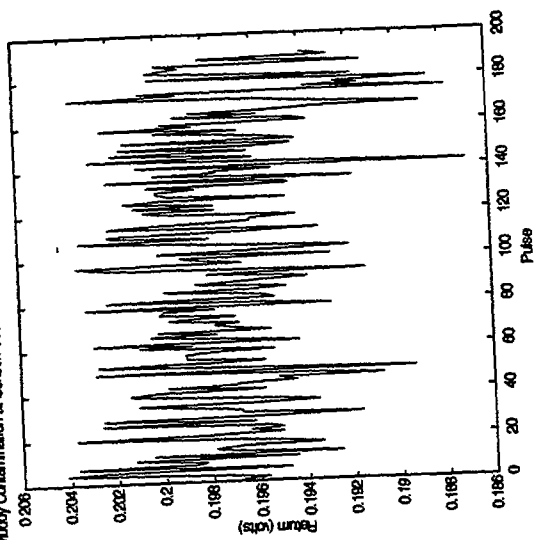
Baseline for Mud Contamination: 9603131.rtf Max Return of Records 1 to 190 Average=0.18165



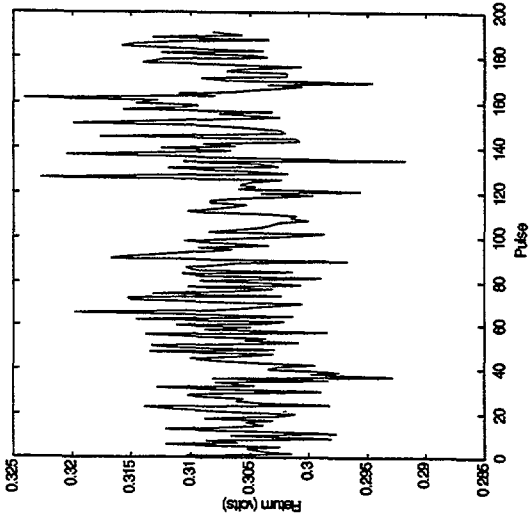
Muddy Contamination at Sensor: 860313h.rtf Records 1 to 190



Muddy Contamination at Sensor: 860313h.rtf Max Return of Records 1 to 190 Average=0.1974



Very Muddy Contamination at Sensor: 960313m.rdf Max Return of Records 1 to 160 Average=0.30657



Very Muddy Contamination at Sensor: 960313m.rdf Records 1 to 100

